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DRAFT
ANNUAL REPORT ON MONITORING OF THE UNSATURATED ZONE AND RECHARGE AREAS AT INEL

to the

State of Idaho INEL Oversight Committee

prepared by

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INTRODUCTION

This project, begun in March 1991, was originally structured as two separate research efforts: an investigation of the recharge phenomenon and surface water-ground water interactions at the INEL; and a study of water and contaminant movement through the unsaturated zone, including a review of computer models used to described this process. During the initial months of work, it became obvious to those involved in these studies that the two topic areas were intimately related, and work since that time has proceeded with no firm boundaries between the two efforts. Graduate students and faculty members associated with the project have therefore been cognizant of most of the separate individual efforts being conducted throughout the project's duration.

Much of the Phase I work (March 1991-March 1992) consisted of a detailed review of available literature pertinent to the two research topics and to the INEL site. These literature reviews continued through Phase II (March 1992-March 993), culminating in a Technical Report, "Abstracts and Parameter Index Database For Reports Addressing the Unsaturated Zone and Surface Water-Ground Water Interactions at the INEL" (State of Idaho INEL Oversight Program Technical Report 93-xx, March, 1993), published separately.

This Annual Report summarizes the other project activities during Phase II, and is organized into three sections:

1. Section I - an overview of the ongoing efforts related to computer model algorithms and data requirements for modeling the transport process in the unsaturated zone (Dr. Jim Liou).

2. Section II - a review of ongoing work to predict the growth and decay of the ground water mound beneath the INEL spreading basins, using the computer model UNSAT-2 (Dr. John Finnie).

3. Section III - a final report of the completed study effort examining the recharge rates associated with stream flow in the Big Lost River, and the effects of this recharge on ground water levels at the INEL site (Dr. Dennis Horn).

Phase III of the project has now begun, and will conclude in December 1993 with two final reports documenting the work that has been briefly described in Sections I and II of this report.

SECTION I

ANNUAL PROGRESS REPORT
MARCH 1993

MODELING TRANSPORT PROCESS IN THE UNSATURATED ZONE

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Department of Civil Engineering
University of Idaho

This progress report will discuss the research and computer modeling efforts which I have performed for the Idaho Oversight Program at the INEL since the beginning of the Fall semester. The work which has been performed consists of researching literature from the INEL and using numerical models to simulate specific problems relating to the transport process in the unsaturated zone. A majority of the work performed has been on verification and benchmarking the USGS developed computer code VS2D, and developing data sets required for simulating specific problems from available site data. The modeling efforts have been based on previous modeling efforts at the RWMC area.

The review of literature performed since the beginning of the Fall semester has been focused into four areas which include: 1) reviewing program documentation for PORFLOW-3, TRACR3D, VS2D, FLASH, and UNSAT-H, 2) reviewing INEL documents focused primarily on the numerical modeling efforts performed at the site, including independent verification and benchmarking of computer codes, 3) reviewing INEL documents focused on the site characterization and acquire representative data files for our modeling efforts, and 4) reviewing documents which deal with sensitivity analysis procedures and probabilistic estimate methods. The literature review on the modeling efforts at the INEL site are primarily focused on the work done by R. G. Baca, S. O. Magnuson, and the Geosciences Unit on the unsaturated zone. Our primary focus has been on a modeling study of water flow in the vadose zone beneath the Radioactive Waste Management complex, performed by the above mentioned.

The modeling efforts performed in this time period have been the primarily focus of our work. A majority of the time was spent on the verification and benchmarking of the US Geological Survey computer code VS2DT and determining the computer requirements needed to run the program. Simulations of the verification problems given in the program's documentation were performed on a PC with a 386 cpu and math coprocessor. However, when we tried to benchmark the program against previous modeling efforts done at the INEL site, the hydrostratigraphic complexity and high grid density of the simulations made the 386 PC ineffective and inefficient in producing results within an adequate time frame. Our efforts were then directed to running the program on a PC with a 486 cpu, and we have recently acquired such a unit. We also made the code to run on a scientific workstation and our benchmarking of the program progressed using this computer. In this process, our modeling efforts used the modeling results from Baca and Magnuson on the past flooding events at the RWMC. Although the actual data set used by Baca and Magnuson was not available, sufficient information was available in their report to perform a similar modeling simulation. The results of the simulations provided adequate results to assure the validity of the program VS2DT.

Presently, our modeling efforts are concentrated on collecting representative data from available literature and determining the probability distribution functions for the input variables in order to incorporate this information into a sensitivity studies of water travel times. Previous studies which accommodate uncertainties in the data have used the Monte Carlo method. We are preparing to perform a simulation using another method developed by Milton E. Harr. This method requires much less simulation and makes it feasible to investigate the consistenty of the numerous data items required in simulating the transport process in the vadoce zone. In the process of doing so, we will provide a check to the results by the Monte Carlo method. Presently, work is being concentrated on establishing probabilistic estimates of various data items.

SECTION II

ANNUAL PROGRESS REPORT
MARCH 1993

GROUND WATER -- SURFACE WATER INTERACTIONS AT INEL

John Finnie
Department of Civil Engineering
University of Idaho

This report summarizes the activities of John Finnie and Damon McAlister under the research grant for the second full year of funding.

Our activities during the second year of the research grant included the following.

1. John and Damon continued efforts to gather and review literature about ground water and surface water at INEL.
2. During the summer of 1992, John Finnie assisted Erik Coats in gathering and interpreting information about flood routing within the spreading basins.
3. In June, John and Damon attended a meeting to discuss issues pertaining to unsaturated zone and surface water-ground water information and activities at the INEL. John presented an outline of the proposed research activities during the second year. He also presented a possible research project involving the use of wetlands to remove radionuclides and heavy metals from waste streams.
4. During the summer, John and Brad King prepared a research proposal to model unsaturated flows at the Central Facilities Area and Radioactive Waste Management Complex. John prepared

a pre-proposal to use wetlands to remove hazardous wastes from INEL waste streams

5. In February, John and Damon attended the Groundwater Quality Technical Workshop in Boise Idaho. They presented research results from the work of Dennis Horn and Erik Coats and preliminary results of their research.

In addition to the above summary of activities, the following report was prepared by Damon McAlister and John Finnie about ongoing activities on our research project.

PROJECT STATUS REPORT

Project Goal: To predict the growth and decay of the ground water mound beneath the Spreading Basins with the variably saturated flow computer model UNSAT-2.

During the summer months, we became familiar with the program UNSAT-2 for use in solving unsteady seepage problems. The program was tested on example problems for both time step and grid size independence by varying these parameters in a given soil column. Since the same results were obtained when these parameters were varied, we knew we had achieved time step and grid independence for these example problems.

Since the results of these problems were deemed satisfactory, UNSAT-2 was then tested against the results of other existing computer programs, i.e. UNSAT-H, FLASH, & FEMWATER. Output results were compared to those published in Baca and Magnuson's "Independent Verification and Benchmark Testing of the UNSAT-H Computer Code, Version 2.0." The test results indicated that UNSAT-2 can be used with confidence in attempting to model surface water - ground water interactions in settings similar to the spreading basins.

Many difficulties were experienced during the program testing. For large array sizes, personal computers could not be used and, in the past, the program had to be run on the university main-frame computer, an IBM 4300. In order to adopt the program to the available computers, minor changes and modifications had to be made to the FORTRAN code to handle large array sizes, to read data input files, and produce output files that could be more easily used. Another draw-back we found was the CPU-time consumed during computer simulations. Large problems with large arrays often took days to complete. It has become obvious that it would be more efficient to use a Cray X-MP model 2/16 supercomputer, like BACA and Magnuson, but we feel that our results are acceptable.

Currently we are working on a one-dimensional flow simulation model of the surface water - ground water interaction at the spreading basins. We are simplifying the stratification in the vadose zone to three soil zones: massive basalt, vesicular basalt, and interbed sediment. Van Genutchen parameters for these soils were obtained from reports on the hydraulic characteristics of soils at the RWMC. We are assuming that 90% of the vadose layer is made up of basalt-flow groups (Anderson and Lewis, 1989). From the normalized distribution of the basalt-flow characteristics, we are assuming the basalt to be 49% massive and 51% vesicular. Average depth to ground water under the spreading basins is 600 ft.

To aid in one-dimensional flow simulations, an analytical ("hand") method using Brooks and Corey equations calculated capillary pressures in the vadose zone and time to steady state flow for a given flux. The analytical results are now being used to verify those produced by UNSAT-2. These analytical methods could be very valuable for determining the sensitivity of the results to changes in the soil parameters. Once reasonable results are established, a two-dimensional model will be created to simulate flow interactions beneath the basins. This model will include more realistic stratification and the effect of sloping of the interfaces between layers.

By December 1993, a final project report will be submitted about the results of the research presently being conducted by John Finnie and Damon McAlister. The results of this research will include a study of: 1) the time required for water to seep from the spreading basins to the ground water, and 2) the effect of sloping basalt flows upon the growth of the ground water mound. The first part of the study will include results of one-dimensional calculations using both analytical and computer techniques, with an analysis of the sensitivity of the results to changes in the relationships between hydraulic conductivity, head, and moisture content. The second part of the study will include results of the two-dimensional computer calculation of flow from the seepage basins through sloping basalt layers to determine travel time, and whether lateral displacement of the ground water mound is being caused by the sloping layers. An additional result of this research will be the completion of Damon McAlister's Masters degree thesis.

SECTION III

DRAFT
FINAL RESEARCH REPORT

SEEPAGE RATES FROM THE BIG LOST RIVER AND EFFECTS ON THE GROUNDWATER AT THE IDAHO NATIONAL ENGINEERING LAB

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March 1993

Seepage Rates from the Big Lost River and Effects on the Groundwater at the Idaho National Engineering Lab

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CHAPTER I

Introduction

The Idaho National Engineering Laboratory (INEL) encompasses about 890 square miles of the eastern Snake River Plain in southeastern Idaho (figure 1.1). Established in 1949 to build, test, and operate nuclear reactors, INEL's primary activities now include testing of various types of nuclear reactors and reactor fuel cells, the processing, consolidation, and temporary storage of nuclear wastes, and various environmental research projects. As a consequence of these operations, tritium, strontium-90, iodine-129, nitrate, sodium, and chloride have been disposed to or have migrated downward to the Snake River Plain aquifer, which is the major aquifer underlying the Snake River Plain (Bennett, 1990). Seepage from the Big Lost River, which flows onto the INEL, can greatly affect the concentration and distribution of these contaminants in the aquifer.

The Big Lost River flows through the INEL. It begins in the Pioneer Mountains and the Lost River Range and flows southeast towards the site, past Arco, and to its terminus (known as the playas) in the northern portion of the site. Flow becomes intermittent past Arco; intermittent because, depending on the magnitude of the flow in the river, sometimes water will reach the playas and other times it will infiltrate well in advance of them. Two causes can be attributed to this phenomenom. First, the channel is lined with highly permeable alluvial deposits, which allows for high seepage rates. Second, the Snake River

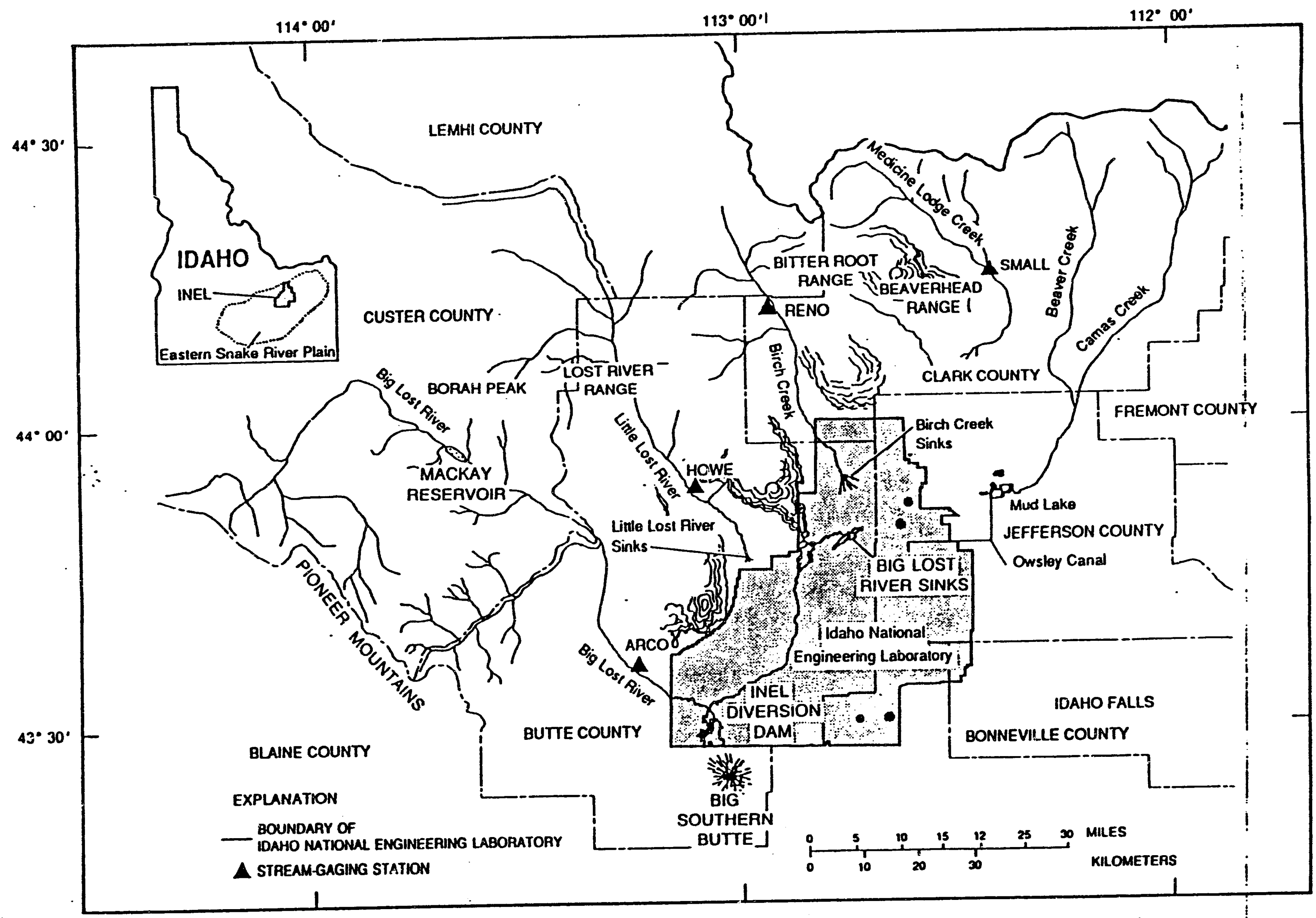


Figure 1.--Location of the Big Lost River and the Idaho National Engineering Laboratory.

fig 1.1

Plain aquifer is at great depths (greater than 200 feet below land). Therefore, seepage from the river feeds the groundwater, but there is no return flow to the river. Since the Big Lost River is highly prone to lose vast quantities of water through seepage, and since seepage can have such a large impact on the groundwater, it is important to identify high seepage areas and quantify the amount of seepage that can be expected. To complete the study, the correlation between seepage and groundwater should be examined because of its potential impact on contaminant migration.

Purpose

There are two primary objectives of this thesis. First is to study seepage rates along the Big Lost River basin from Arco through the INEL to the playas, determine seepage functions for select reaches based on daily flows, and develop a daily seepage record for these reaches. Second is to study the effects of seepage on the regional groundwater system and develop relationships between seepage and groundwater levels. The years included in the study are 1969-1976 and 1983-1987.

Two similar studies have been performed on the Big Lost River and Snake River Plain aquifer beneath the INEL, but they both had limitations. Bennett (1990) used monthly streamflow data to obtain seepage functions, and did not attempt to develop equations relating seepage to groundwater levels. Nace and Barraclough (1952) did not develop any equations for seepage or seepage-groundwater correlation, and because substantial groundwater data were not available, only stated some general conclusions regarding flow in the river and corresponding groundwater levels. This study has substantially more data than available to Nace and Barraclough, and uses daily rather than monthly flows.

Objectives

The specific objectives of this thesis are as follows:

1. Collect streamflow data for the Big Lost River and groundwater level data for the INEL.

2. Determine daily seepage rates for the Big Lost River and seepage equations for river reaches using regression analyses. Develop a daily seepage record.

3. Correlate seepage with groundwater levels.

CHAPTER II

Big Lost River Basin

The Big Lost River flows out of the Pioneer Mountains and the Lost River Range onto the eastern Snake River Plain near Arco, Idaho, draining about 1500 square miles (see figure 1.1). Flow in the river is controlled by Mackay Dam, an irrigation reservoir 30 miles upstream of Arco near the town of Mackay, Idaho. Between Mackay Dam and Arco there are numerous irrigation diversions that operate between April and September. Much of the flow in the river is diverted for irrigation upstream of Arco, and therefore water reaches the Snake River Plain only during higher water years or large flood events.

During higher water years, water will flow past Arco and eventually across the western boundary of the INEL. Here the river flows out of a narrow canyon and into a channel that is 200- to 300-feet wide and cut into the plain less than 20 feet deep. This is in contrast to the 60 foot cut just downstream of the Arco gage. Approximately 6.5 miles downstream from the boundary the river is split by the INEL flood diversion system, which was constructed in 1958 and enlarged in 1984 (Bennett, 1990). Here an earth dam diverts flow from the river into four spreading areas, A, B, C, and D (figure 2.1), where water is allowed to both seep into the ground and evaporate. Gates in the dam permit undiverted flow to continue onto the site.

As the river flows northward, the channel continues to be less incised into the plain. Near highway 20, 6 miles downstream

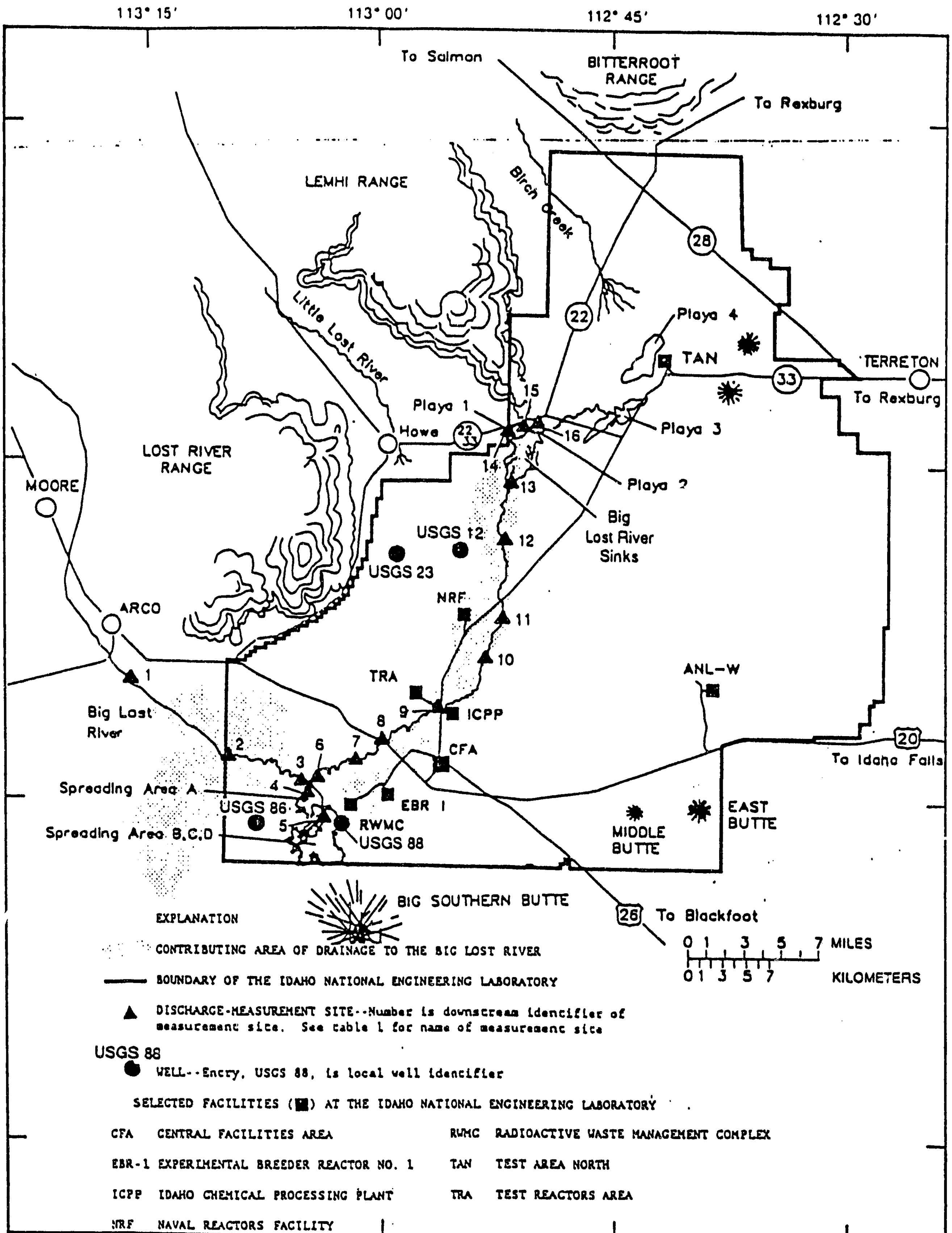


Figure 2.--Location of selected discharge measurement sites, selected wells, and approximate contributing drainage area to the Big Lost River at the Idaho National Engineering Laboratory

fig. 2.1

of the diversion dam, it cuts in less than 10 feet, and downstream of highway 20 the river settles into a floodplain 1 to 4 miles wide.

Finally, as the river nears the playas, flow splits into a number of small channels that lead to the terminus. The playas (figure 2.1), named simply 1, 2, 3, and 4, have areas of 350, 110, 1000, and 1350 acres, respectively. Only during extremely high water years does flow reach the playas.

Spreading Areas

In the early 1950s there was some flooding both at the TRA and ICPP (McKinney, 1985). These incidences, along with other research and investigation, prompted the need for flood protection for the INEL site.

The original flood detention system was built in 1958. It was designed to divert 1000 cfs out of the main river channel into the spreading areas (McKinney, 1985). As already stated, there are four cells to the system: spreading areas A, B, C, and D. Water first flows into A, then progressively passes through the next three as each basin fills up.

A large runoff event in the spring of 1965 was approximately double the flood diversion design event (55 years, as later determined). All four basins nearly filled up, and it took about a month to subside. This event both proved the need for the diversion areas, as well as the need to expand them. It also showed there was the need to detain the water for several months, rather than a few days as the system was designed for. In 1966 some minor work was performed to the system to ensure it could detain flows for longer periods of time.

Much research has been performed on the system. In 1969, Lamke determined stage-discharge relationships for both the flood diversion system and the Big Lost River. A report in 1972 summarized P.H. Carrigan's results for a study on the probability of exceeding the flood diversion system. He determined that it would be exceeded once every 55 years, and that if the capacity of the diversion channels were doubled the system would take a 300 year storm event.

In late 1983 and early 1984 there was another flood threat on the site, and again the flood diversion system was tested. Details of the event are very lengthy, but in summary, air temperatures dropped well below 0°F and ice formation in the diversion channel nearly caused overtopping of the dike. An extensive work force eventually got the problem under control without too much damage to the system. Due to this near catastrophe the detention system was upgraded in 1984 to handle a peak flow of 5300 cfs.

Snake River Plain Aquifer and Geology

General

The eastern Snake River Plain is a structural basin 200 miles long and 50 to 70 miles wide. The INEL lies in the west-central portion of the plain, and is underlain by Tertiary and Quaternary volcanic rocks interbedded with sediment deposits that include clay, silt, sand and gravel. The sequences of rock and sediments are greater than 10,000 feet thick (Rightmire and others, 1987).

The Snake River Plain aquifer is a groundwater reservoir that may contain more than 1 billion acre-feet of water (Barraclough and others, 1981). The aquifer can be very productive, producing several thousand gallons per minute from the basalt-sediment sequences with little drawdown. It is comprised of fractured basalt flows interbedded with sediment deposits. Transmissivities range from 134,000 to 13,400,000 ft^2 per day (Robertson and others, 1974, p. 12). Depth to water is 200 feet in the north and 900 feet in the south, with a groundwater flow direction from northeast to southwest. The effective base of the aquifer likely coincides with the top of a thick and widespread sequence of clay, silt, sand and basalt (Anderson, 1990). For well INEL-1, a very deep observation well on the site, this sequence is found to begin at 1220 feet below the land surface (Mann, 1986). In other wells on site it ranges from depths of 800 to 1500 feet. This suggests the effective aquifer thickness varies from 600 to 800 feet in most places, based on the fact that the assumed base of the aquifer slopes from northeast to southwest, nearly parallel with the slope of the water table (Anderson, 1991).

ICPP, TRA, and RWMC

The Radioactive Waste Management Complex (RWMC) is a facility for the storage of radioactive and chemical wastes. Low-level and transuranic waste is buried in shallow pits and trenches. The Idaho Chemical Processing Plant (ICPP) is used for reprocessing of spent nuclear fuel rods, and the Test Reactor Area (TRA) for nuclear research.

All three sites and their immediate surroundings are underlain by many basalt flows, basalt-flow groups, and basalt-flow units. A basalt flow is a solidified body of rock that was formed by a lateral, surficial outpouring of molten lava from a vent or fissure (Bates and Jackson, 1980). A basalt-flow unit is a separate, distinct lobe of lava that issues from the main body of a lava flow (Bates and Jackson, 1980). A basalt-flow group is a sequence of one or more petrographically similar flows or flow units that are extruded from the same vent or magma source within the course of a single eruption or multiple eruptions during a relatively short interval of time (Kuntz and others, 1980). There are many basalt groups, with thicknesses up to 114 feet, that either lie directly over older groups or are separated by a sediment bed, which may have been deposited during volcanic inactivity. There are some major sediment beds, ranging up to 50 feet in thickness and containing poorly to well sorted layers of clay, silt, sand and gravel. Depth to water at the TRA and ICPP sites ranges from 430 to 480 feet, whereas it is approximately 600 feet at the RWMC. Zones of perched water are found at all sites. At the TRA and ICPP sites they are a result of seepage from percolation ponds and at the RWMC they are caused by seepage from the diversion ponds, which are south of the RWMC.

Hydrologic Implications

The many basalt flows all are fractured to some degree and depth, which allows water to move vertically and horizontally, and which also can create zones of perched water. Sediment beds facilitate or retard the movement of water, depending on the sorting and grain sizes. When water becomes perched, it may move horizontally until finding either a more permeable zone, a vertical fracture or a well open to deeper depths.

The area just north and east of the TRA and ICPP has experienced significant uplift, which caused fracturing of the sediments and basalts. Because of this, the hydraulic conductivity has increased and groundwater responds more rapidly to recharge. Also, many of the older flow groups throughout the site have experienced tilting, folding and thus fracturing. All of this complicates the mechanisms of unsaturated flow, and makes it difficult to predict the flow of water from the ground surface to the groundwater.

Climate

In general, the climate at the INEL is considered semiarid, with annual precipitation very light. Average annual precipitation is 9.07 inches, with maximum 24-hour and 1-hour values of 2 inches and 1 inch, respectively. Snow does fall on the site from mid-November to mid-April, and the average annual snowfall is 26 inches. The largest depth ever measured at the site is 27 inches. Average monthly maximum temperatures range from 87°F in July to 28°F in January, and average minimums range from 49°F in July to 4°F in January.

CHAPTER III

Groundwater Recharge

Many models have been developed to determine groundwater recharge. A basic approach is presented by Freeze and Cherry (1979). They state that if we limit ourselves to watersheds in which the surface-water divides and groundwater divides coincide, and for which there are no external inflows or outflows of groundwater, the water-balance equation for an annual period would take the form:

$$P = Q + E + \delta S_s + \delta S_G$$

where:

P = precipitation,
Q = runoff,
E = evapotranspiration,
δS_s = change in storage of the surface-water reservoir,
δS_G = change in storage of the groundwater reservoir (both saturated and unsaturated).

This is a very simple approach to the interactions between groundwater and surface water. Other, more complex models have been developed based on this equation. Most primarily examine recharge from agriculture activities, although some include canal and stream losses. Also, some models consider just the saturated zone while others integrate both the unsaturated and saturated zone. Most significant and reliable models include both processes.

Freeze (1969) developed a one-dimensional, vertical, unsteady, unsaturated flow model for groundwater recharge. The model calculates runoff and the amount of infiltrated water after irrigation and precipitation. It then relates the unsaturated zone processes of infiltration and evaporation to the saturated zone processes of recharge and discharge. Freeze defines these processes as follows. Infiltration is the entry into the soil of water made available at the ground surface, together with the associated downward flow. Evaporation is the removal of water from the soil at the ground surface, together with the associated upward flow. Recharge is the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. Discharge is the removal of water from the saturated zone across the water-table surface, together with the associated flow toward the water table within the saturated zone.

As stated, water table fluctuations occur when a change in recharge or discharge is not compensated by a change in infiltration or evaporation. Controlling parameters in the model include: rate of rainfall or evaporation, duration of rainfall or evaporation, soil type, antecedent soil moisture conditions, groundwater recharge or discharge rate, depth to the water table, and depth of ponding. This model requires extensive data and time to set up and run.

Burrell (1987) developed a computer model for the Oakley Fan area of southern Idaho. The goal was to determine the amount of recharge to the groundwater system from deep percolation and canal seepage in the irrigated portions of the study area (Burrell, 1987). Recharge was calculated for grids of one-half mile square. The model included the effects of evapotranspiration, change in soil moisture, deep percolation, and canal and stream seepage losses, and was based on a monthly timestep. Deep percolation is calculated using the net irrigation application plus precipitation minus evapotranspiration, and requires that hydraulic conductivity be calculated if flow is unsaturated. The Brooks-Corey relationship is used to calculate the unsaturated conductivity, and it requires the displacement pressure and the capillary pressure in each soil layer.

Only two examples of unsaturated-saturated recharge models are discussed here, but they demonstrate the complexity involved when including the unsaturated zone. Hydraulic conductivity must be calculated, and since it varies with capillary pressure, measurement probes need to be installed at different locations within the unsaturated zone. Soil moisture is also needed and must be measured similarly to capillary pressure. These are only a few of the parameters required for the unsaturated zone, but they demonstrate how extensive the unsaturated zone must be monitored to run an unsaturated - saturated recharge model.

Seepage Estimation Methods

Three primary methods are used to measure seepage from a river or canal. They are the ponding method, the inflow-outflow water balance method, and the seepage meter method. There are advantages and disadvantages to each method depending on the area of study and the type of information available.

The ponding method requires construction of temporary bulkheads across each end of a channel to impound water for measurement. Once they are in place, the experimenter then monitors the change in water depth in the impoundment. Seepage is calculated by determining the total volume of water that leaked out during the monitoring period.

This method can only be used under special circumstances because impoundment of a stream or canal cannot easily be done, and bulkheads are very expensive and take time to install. Also, results from this method have some drawbacks. If the reach impounded is too long, the measured seepage rate is only an average, and any high rate seepage areas are not located. Also, impoundments allow for greater sedimentation, which can seal, to a degree, the wetted perimeter. Therefore the seepage rates measured could be lower than if influenced by currents. Seepage is also controlled by the wetted surface area and hydraulic head. Ponding can increase water depth and the wetted area, so calculated seepage rates could be skewed higher than exist naturally. Increased head forces more water into the soil, which speeds up and increases the depth of soil saturation. When a soil becomes saturated, water flows more readily through the strata because the soil-water tension has been decreased and voids have been filled. Increased wetted area provides more surface area for the water to escape through.

Despite the problems associated with the results from this method, it does yield the most reliable results for average reach seepage, compared to other methods, because all inputs and outputs can be accurately measured.

A simpler approach to seepage estimation is the inflow-outflow method, which measures seepage using a water balance approach. All inflows and outflows from the experimental reach are recorded, and seepage becomes inflow minus outflow. In-stream flow must be measured as well as any diversions, return flows, leaks, and spills from the watercourse. Accuracy for this method relies entirely on the accuracy of the flow measurements. To minimize any inaccuracies in measurements, long reaches should be used. Seepage from the watercourse then outweighs the errors in measurement.

The inflow-outflow method is best applied when only average reach seepage rates are needed, because it is the easiest to use. The data, inflows and outflows, are generally available, provided most inflows and outflows are already gaged, so little extra setup of measuring equipment is required. However, it cannot be used to determine high or low loss areas in a reach because measurements are not that accurate in short reaches.

A third seepage estimation method is seepage metering, which consists of monitoring seepage meters installed in the bed of a watercourse. With such meters, seepage can be measured for small areas. An advantage is that seepage can be measured throughout the year because the meters require no special operating conditions, as does the ponding method. This technique cannot be used in rocky areas because the bed material must seal around the cup. Also, to obtain a reliable average value of loss for a river reach, measurements must be made at many locations. This method is considered to provide good quantitative results when applied correctly, but is used primarily to locate high and low seepage areas rather than average reach seepage rates.

Netz (1980) applied the inflow-outflow method to determine seepage from canals in southeastern Idaho. Flow measurements were broken into two groups. Either they met all specified criteria set by the author, and were "prime time measurements" (Netz, 1980), or they violated one or more criteria. These criteria were adopted to eliminate some of the errors of seepage measurements, and they were as follows (Netz, 1980):

1. Water measurement conditions are such that no more than ±5 percent error in flow rates can be expected.
2. The canal stage is low and fluctuating no more than 0.02 feet during the time the measurements are being made.
3. The reach of the canal is long enough to assure that the accumulated error due to water measurement will not be over ±75 percent of the measured outflow due to seepage.

All collected flow data were separated into their respective groups and analyzed statistically to determine the reliability of the measurements. Statistics were calculated using a computer program called Statistical Analysis System. In this program a general linear model was applied to the data, with seepage dependent on canal bottom type, soil type, and season of measurement.

Results of the study showed that the "prime time measurements" gave the best results, and that the inflow-outflow method was best applied during very low flow periods when the "prime time measurement" criteria could be met. Also, Netz determined that the factors used did not show a high enough significance to be predictive parameters of seepage, and that the study did not suggest that a mathematical model could be applied to the study area to predict seepage. Netz noted that groundwater was high in some areas of study and could have had a large impact on canal flow.

Previous Site Research

In 1990, C.M. Bennett, then employed by the USGS, researched streamflow losses for this section of the river and wrote a report detailing his results. The period of time he examined was July 1972 to July 1978 and July 1981 to July 1985. Seepage losses in acre-feet per month were calculated for river reaches between streamflow gages using the inflow-outflow method and monthly flow data from the river gages. Seepage was defined simply as the monthly flow at the upstream gage minus monthly flow at the downstream gage. Four reaches, or areas, were examined: the Arco gage to the INEL diversion dam, the diversion spreading areas, below the diversion dam to Lincoln boulevard, and Lincoln boulevard to the playas. Equations to predict flow at downstream gages based on flow at the next upstream gage were also developed for the reaches from the Arco gage to INEL diversion dam, and the INEL diversion dam to Lincoln Boulevard.

Monthly flows were plotted with the upstream gage on the x-axis and the downstream gage on the y-axis. A regression analysis was run on these data with the upstream gage as the independent variable, and regression equations developed. The resulting equations were nearly linear, with r-squared values of 0.990 and 0.987, respectively. Regression analyses were not run on the other two reaches because there either was not enough data available or regression analysis did not apply.

Four wells were used to examine the relationship between flow in the river and groundwater level changes. Well hydrographs were presented and compared to high and low river flow periods. No attempt was made to correlate the relationship between flow in the river and groundwater levels with equations; only general discussion was made.

Nace and Barraclough (1952) also studied recharge from the Big Lost River. During the second half of 1951 there was very high runoff in the Big Lost River, which permitted study on seepage from the Big Lost River. At that time only one gage was permanent (the Arco gage), so ten temporary measuring sites downstream of Arco were established. Daily flow measurements were taken at Arco and periodic measurements (3 to 5 times between the months of August and November) were taken at the other sites during the periods of high flow. River reaches were defined as reaches between measuring stations, and seepage rates for each reach were calculated on days when measurements were made at all stations. Units of seepage were in cubic feet per day per square foot, using river cross sections and stadia measurements to obtain cross sectional area. Groundwater levels were monitored, but since the event was so short-lived no direct conclusions could be drawn. Based on the streamflow at the Arco gage, the total daily and annual amounts of recharge, minus an assumed two percent loss for evapotranspiration, were estimated by assuming all flow past Arco either sank into the ground or evaporated.

CHAPTER IV - SEEPAGE ESTIMATION

Introduction

The selection of appropriate seepage estimation methods for the Big Lost River was a critical step in meeting the objectives of this study. Although different methods were reviewed for application, factors such as data availability and accuracy limited the potential methods to those which would yield "lumped", or average daily, seepage rates for the different reaches along the river. A traditional technique, the inflow-outflow method (previously described), was selected for each river reach where flow rates were available at both ends. For the spreading areas, where the inflow was known but the time-rate of outflow (seepage and evaporation) was not measured, other, less accurate methods were explored, and will be explained in further detail later.

Results from this portion of the study included the development of seepage equations and the calculation of daily seepage values for the entire period of study for all the defined river reaches and spreading area. These daily seepage values were then later used to compare seepage and groundwater levels, as determined from selected well data.

To estimate seepage from the river, reaches had to be defined and corresponding streamflow data obtained. All available streamflow gage data for the Big Lost River were collected and reviewed. Time was spent studying Bennett's report (1990) since his work was recent and similar to the research in this study. It seemed reasonable to consider using similar study reaches. Primary requirements in the delineation of reaches were that all flow into or out of each reach must have been measured, and records of these flows are available for extended periods of time. Extensive prior records were necessary for two reasons. First, there was no time to perform field flow measurements, and most important, due to extended drought conditions, there had been little or no flow in the Big Lost River below Arco in recent history. Also, to develop justifiable equations and results, a long period of record was necessary because hydrology is very probabilistic, and short periods of time do not fully demonstrate the possible variations in hydrologic conditions.

Study reaches were apparent after a study of gage locations and Bennett's report. Gages with extended periods of record were located at Arco, just below the entrance into the diversion areas, just below the diversion dam, and at Lincoln Boulevard. In addition, a gage record could be synthesized upstream of the diversion dam by summing flows from the gages below the dam and into the diversion areas. Since these were the only gages available below Arco, their location defined study reaches, and they were the same as those used by Bennett. This permits the results of this study to be compared with those obtained previously.

In summary, the reaches used in this study were as follows: reach 1 was from Arco to upstream of the diversion dam, reach 2 was from below the diversion dam to Lincoln Boulevard bridge, and reach 3 was from Lincoln Boulevard bridge to the playas. Figure 4.1 shows a schematic of the study area, including the river gage locations, reaches, spreading areas and the approximate locations of the wells used to study seepage/groundwater relationships.

For each river reach defined, inflow and outflow data were available, with the exception of some irrigation return flow just below Arco and any surface runoff. However, irrigation return flow is apparently minimal. Bennett stated (1990) that miscellaneous measurements indicate that return flow during the irrigation season probably is less than 1 cfs. There were times during the period of study when return flow and/or surface runoff caused flow to increase in a reach, but it was not often (13.8% of the time in reach 1 and 11.2% of the time in reach 2), and as will be explained later, seepage for these days was determined differently than for other days.

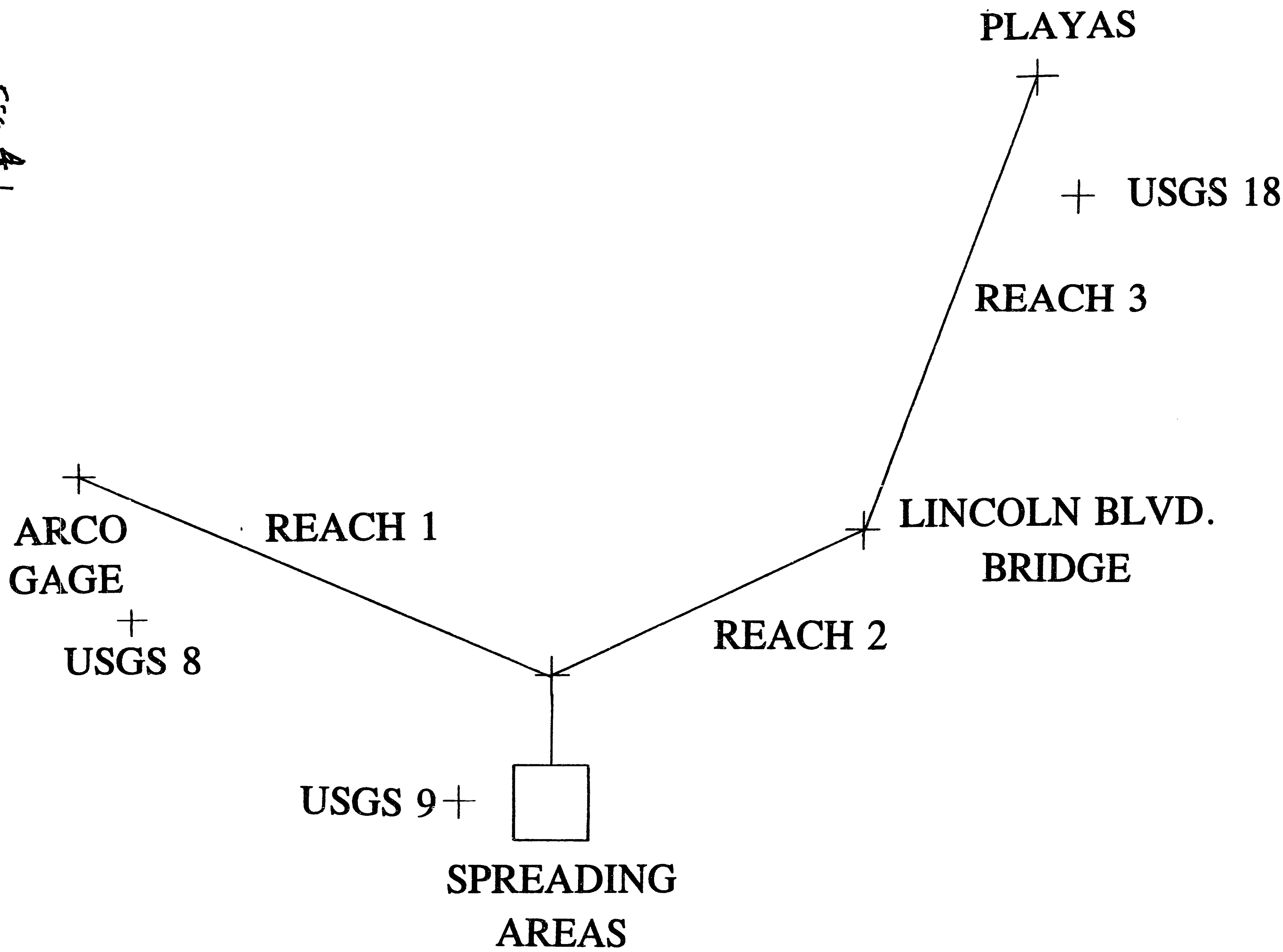
Seepage Estimates for River Reaches

Using the inflow-outflow method, seepage in a reach can be defined as:

$$S = Q_1 - Q_2 + \Sigma q$$

where S is the average daily seepage, Q_1 and Q_2 are the mean daily upstream and downstream flow rates, respectively, and Σq represents the sum of all other inflow (runoff, return flow) and outflows (evaporation, water withdrawals). With no data available to estimate Σq (termed "local inflow") with any accuracy, and with the results of other studies indicating that most of the time local inflow is probably small, it was therefore

Fig 4.1



PLAYAS
USGS 18
REACH 3
LINCOLN BLVD.
BRIDGE
REACH 2
REACH 1
ARCO
GAGE
USGS 8
USGS 9
SPREADING
AREAS

assumed that as long as Q_1 exceeded Q_2, Σq could be considered equal to zero. However, for those days when Q_2 was greater than Q_1, this seepage equation could not be applied without resulting in a negative seepage rate (outflow from groundwater), which is unrealistic, given the depth to groundwater. It therefore became necessary to use another method of estimating seepage for these days, since an entire set of daily seepage values was necessary for the second portion of the study, comparing seepage and groundwater levels.

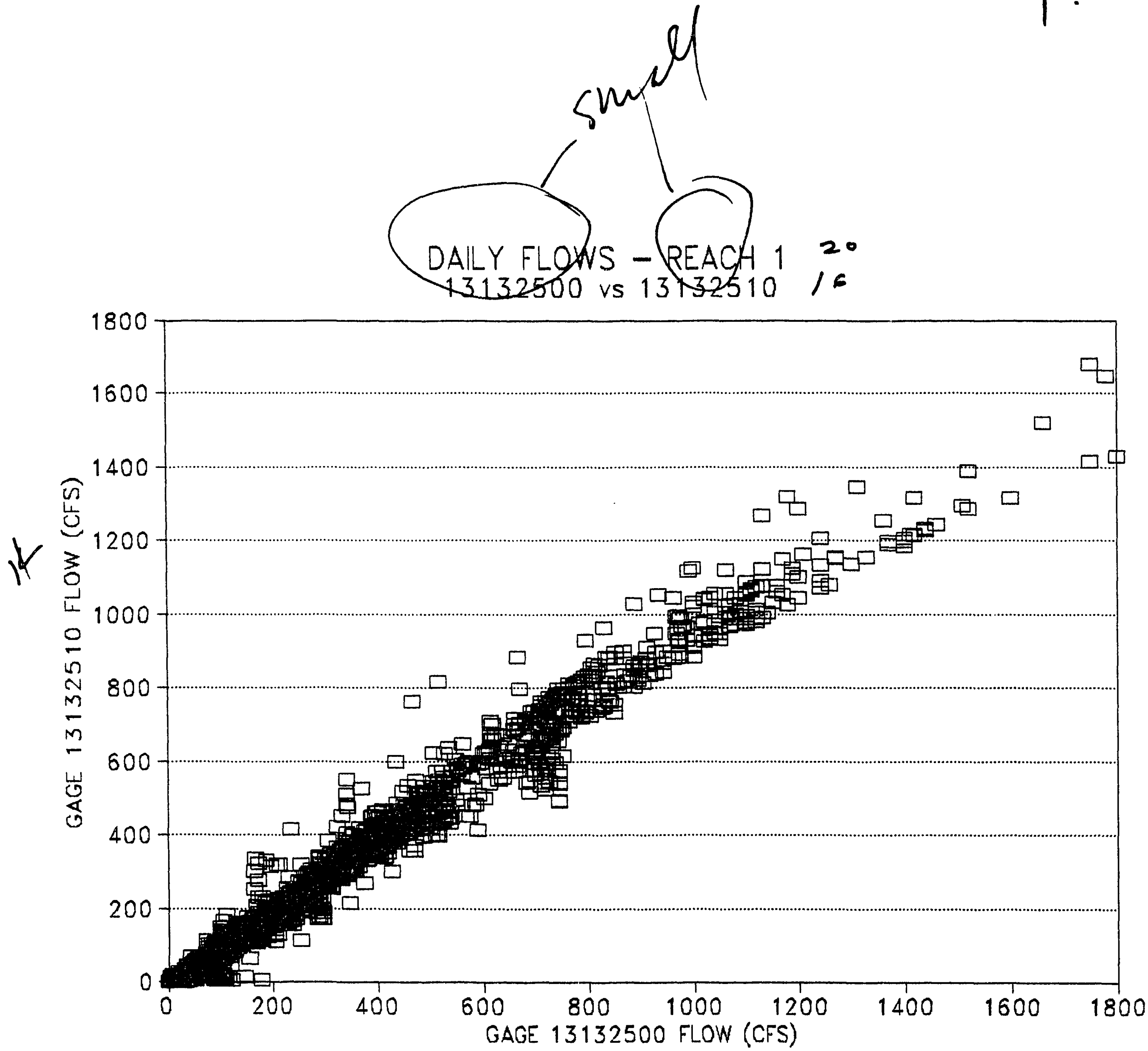
After examining various alternatives, it was eventually decided to use regression analysis to develop, for each reach, an equation that would estimate the daily seepage rate that might be expected if the Σq term in the seepage equation was indeed equal to zero. This equation could then be used in lieu of the inflow-outflow method for those 10-15% of the days with apparent negative seepage.

As an initial attempt to develop these seepage equations, the relationship between Q_1 and Q_2 for each reach was closely examined. Previously, Bennett had ascertained there was a linear relationship between monthly upstream and downstream flows, both in reaches 1 and 2. Scatter plots of daily flows for the same reaches, upstream gage against downstream gage, demonstrated a similar linear relationship. It was therefore postulated that a linear regression in the form of $Q_2 = f(Q_1)$ could be used to estimate downstream flow, given the upstream flow, and this estimated value then used in the previous seepage equation in place of the measured Q_2.

Initially, it was assumed that all daily flows should be used in developing these regression equations, including those days when downstream flow exceeded upstream flow. As hypothesized, if all flows were included, then the equations would be more accurate. A linear regression was therefore performed using the data for each reach, with downstream flow dependent on upstream flow. Linear regression, rather than nonlinear, was selected because only two variables were involved in the analysis, and a linear relationship had already been suggested by both the scatter plots of the data and by Bennett's study. To evaluate the results of these regressions, the r-squared (r^2) value was used to indicate the fraction of the total variation in the dependent variable that is explained by the independent variable. The closer r^2 is to one (r^2 can be any number between 0 and 1), the more successful the linear regression model is in predicting values of the dependent variable. In other words, the higher the r^2 the more linear correlation between the two variables. As might be expected, the regressions for both reach 1 and 2 indicated strong linear correlation between upstream and downstream flows, with r^2 values of 0.98 and 0.98, respectively. Scatter plots of the data for both reaches 1 and 2 are shown in figures 4.2 and 4.3.

After evaluating the results of the regression, and examining the application of the equations to estimate seepage,

1.

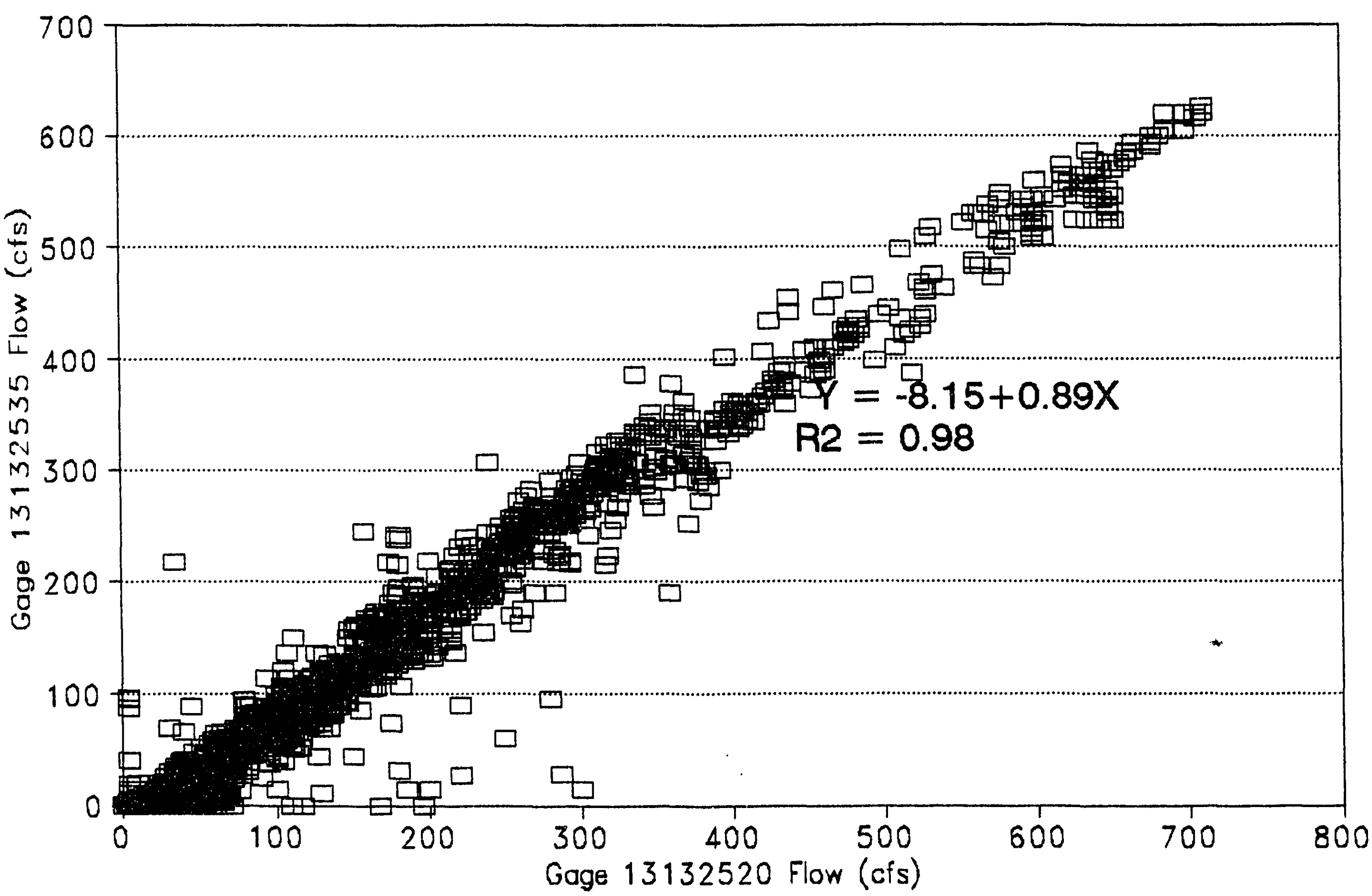


small
DAILY FLOWS - REACH 1
13132500 vs 13132510
GAGE 13132510 FLOW (CFS)
GAGE 13132500 FLOW (CFS)
0
200
400
600
800
1000
1200
1400
1600
1800

14

fig. ~~3.1~~ 4.2

Daily Flows – Reach 2
13132520 vs 13132535



it was concluded that there were at least two problems with the selected approach. The use of all data values in the regression analysis, including those days when downstream flows exceeded upstream flows, introduced two separate populations of the independent variable: one in which there was no local inflow into the reach, and one which included local inflow. Since the objective eventually was to estimate seepage for days with Q_2 greater than Q_1 by predicting Q_2 without local inflow, it was decided to eliminate all daily data with Q_2 greater than Q_1 from subsequent regression analyses.

The second problem with the completed analyses was disclosed after examining numerous instances where the upstream flow was fairly constant, but the downstream flow fluctuated significantly. With the proposed approach, a constant value of Q_1 would always yield the same value of seepage, since Q_2 is based only on the value of Q_1. Therefore, attempting to correlate only downstream flow with upstream flow provided useful insight for the study, but not necessarily useful results. It should be noted here that with this much data and river conditions such as these, with no significant inflow from tributaries or groundwater, a regression of this sort performed on most river reaches should produce similar results because the flow would always decreases downstream due to seepage.

Since the first approach was an indirect attempt to develop a seepage equation, it was decided, after further study, that a more direct approach was necessary. Seepage was obviously a function of flow in the river reach, but not necessarily only upstream flow. It was concluded that a more reasonable choice might be the average flow in the reach. Larger average flows mean increased depths throughout the reach, and increased depth means more wetted area, so seepage would increase with flow. When small local inflows create increased flows downstream (although still less than upstream flow), seepage would be greater than if overland flow was zero because the average flow in the reach would be greater. Therefore, a new model of the seepage process was adopted:

$$S = f(Q')$$

where Q' represents the average daily flow in the reach, calculated by averaging each day's flow at the upstream and downstream gages (excluding those days when downstream exceeded upstream), and S represents the difference between the upstream and downstream flows. Using this model, a linear regression of S on Q' results in the following equation:

$$S = \beta_0 + \beta_1 * Q'$$

where:

S = seepage in the reach, cfs
Q'= average flow in the reach, cfs
β_0, β_1 = regression coefficients, unitless

The drawback to this approach is that both the dependent and independent variables (S, Q') are a function of the two other variables (Q_1, Q_2), which are in turn strongly correlated. This results in a regression analysis that does not meet all statistical regression criteria, and may introduce spurious correlation. However, the model was nevertheless believed to be a valid representation of the seepage process, defined by the inflow-outflow method. Since the ultimate use of the equation was to estimate seepage for less than 14% of all the daily values, the overall validity of the total seepage data set should not be significantly impacted by errors from this approach.

<u>Results: Reach 1</u>

Using the previous regression equation applied to the data for reach 1 resulted in the following regression coefficients:

$$r = 0.63$$
$$r^2 = 0.40$$
$$\beta_0 = 10.201$$
$$\beta_1 = 0.080$$

A scatter plot of the data, S versus Q', is presented in figure 4.4, indicating that although there is some observable linearity, it is significantly less than the observed relationship between Q_1 and Q_2 (figure 4.2). Out of the total of 4,089 plotted points in figure 4.4, there are a few dozen obviously apparent outliers, which deserve a brief discussion.

The Big Lost River is aptly named because flow sinks and returns quite often as it approaches Arco. Below Arco the groundwater reservoir drops to much greater depths, depths to which it can no longer feed the river. Because of this, and depending on the amount of flow in the river, there are times when all the water passing Arco sinks before it reaches the INEL diversion dam. As a result of this situation, in the plot of average daily flow versus daily seepage, it can be noticed that seepage at times exceeds average daily flow. The explanation of smaller.

2.

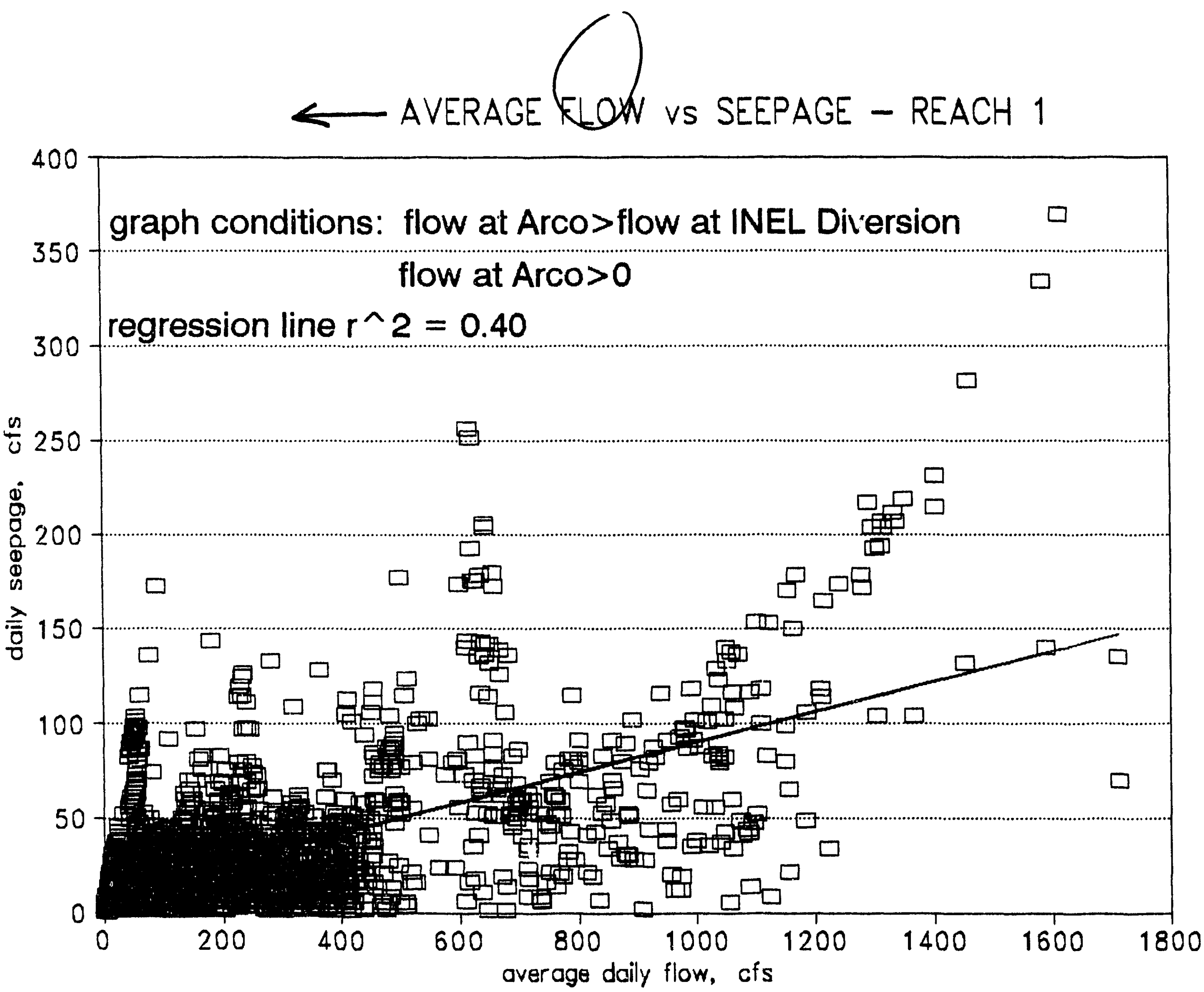


fig. 4.4 ~~3.3~~

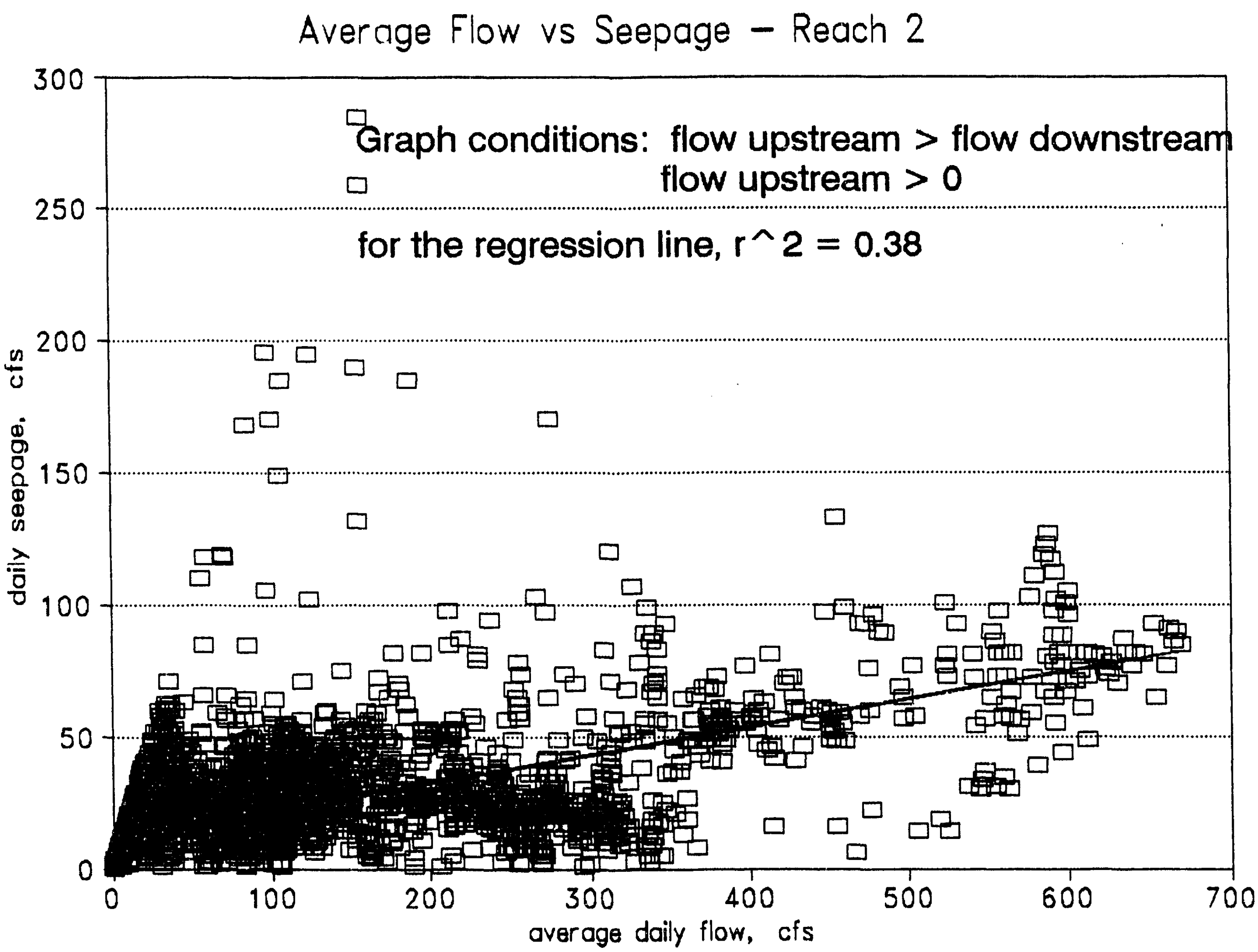
this phenomenon is obvious. If 400 cfs passes Arco but completely sinks completely soon after, average daily flow is 200 cfs but seepage is 400 cfs. This is the cause of most of the extreme outliers seen in figure 4.4. To perhaps resolve this problem, another approach considered for the study was to perform the same analysis on only those days when flow was registered at both upstream and downstream gages. However, it was decided that seepage is seepage, whether all the flow or some of the flow seeps into the ground, and it is debatable whether this other approach would have given a more linear plot, or a more representative model of the system.

It must also be kept in mind that the data in figure 4.4, and the associated regression equation, do not include those days when downstream flow exceeded upstream flow. The equation was applied, however, to those days to calculate the daily seepage. This resulted in a complete data set of seepage values for reach 1, enabling the seepage-groundwater correlation analyses to then be performed (described in Chapter V). Despite this approach not being entirely accurate, the equation generated was only applied to 13.8% of the days in reach 1.

Results: Reach 2

For reach 2, seepage versus average daily flow is plotted in figure 4.5. As with reach 1, the linearity in the plot is obvious, especially if the few dozen outlier points are eliminated (4,212 points are plotted here). The cause of these

12.



Average Flow vs Seepage - Reach 2
Graph conditions: flow upstream > flow downstream
flow upstream > 0
for the regression line, r^2 = 0.38
daily seepage, cfs
average daily flow, cfs
0
50
100
150
200
250
300
0
100
200
300
400
500
600
700

fig. ~~3.4~~ 4.5

outliers has been previously explained. Regression coefficients for this reach were:

$$r = 0.62$$
$$r^2 = 0.38$$
$$\beta_0 = 11.310$$
$$\beta_1 = .106$$

using the same form of regression equation previously discussed. With this equation applied to the 11.2% of the days in which downstream flow exceeded upstream flow, a complete set of daily seepage values was again obtained.

<u>Results: Reach 3</u>

No analysis was appropriate for this reach, since all the water seeped into the ground between Lincoln boulevard and the playas, and no streamflow gage data was available for the playas prior to 1985. This made it impossible to perform an analysis similar to reaches one and two. Therefore, for the seepage-groundwater analyses, seepage was equal to the flow recorded at Lincoln boulevard. This was not the most accurate method to estimate seepage, since at times in the past large volumes of water have ponded in the playas, making the situation would be similar to that of the spreading basins, but it was the best that could be offered.

Seepage Estimation for the Spreading Areas

A schematic of the spreading areas, including the storage volumes estimated for each basin, is provided in figure 4.6. The seepage beneath these spreading areas is important to an overall understanding of the groundwater recharge at INEL. Because large volumes of water may be diverted from the Big Lost River and

2 Seepage Simulations:

1. Volume of each pond drained after 1 month.
2. Volume drained after 2 months.

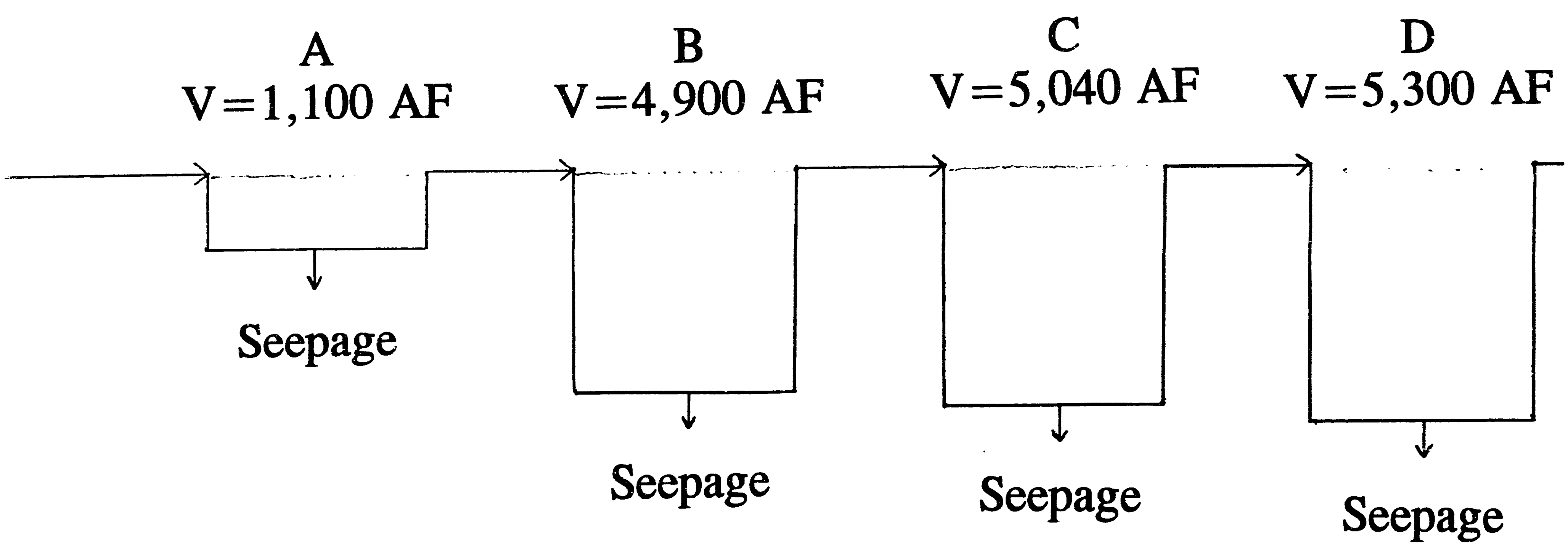


Fig. ~~3.5~~ 4.6

permitted to enter the ground in a limited geographic area, the potential to affect critical sites such as the RWMC (in close proximity to the spreading areas) is significant. During periods of high flows on the river, much of the seepage within the INEL boundaries may take place in these basins, and correlation studies between seepage and groundwater should reflect this. Therefore, seepage equations for the spreading areas are necessary if these seepage quantities are to be estimated.

Unfortunately, determining seepage in the spreading areas is a more difficult task compared to that for the river reaches. A simple inflow-outflow approach could not be applied to this area since water ponds as storage volumes, rather than flowing continuously through. Instead, daily flows were routed through each basin, seepage equations were used to calculate daily seepage per basin, and total daily seepage was then estimated as the sum from all the basins. To accomplish this procedure of flow routing throughout the system of spreading basins, several prior studies were carefully examined to develop routing and seepage parameters.

P.H. Carrigan (1972) developed a computer program to route flows down the Big Lost River to the diversion dam, through the spreading areas, and also on down to the playas. His report studied the probability of exceeding the capacity of the spreading area flood-control system. To properly route flows through the spreading area he developed seepage equations for each of the four basins. These equations were extracted from his computer code and an attempt was made to apply them to this study. In his equations, seepage was a function of both a unit seepage-evaporation loss rate determined by Carrigan and depth in the basins. For some unknown reason his equations produced questionable results when applied to the data in this study. After further review of Carrigan's report, it was noticed that once flow into a basin stopped, water in each basin appeared to seep instantly, signifying no lag time for seepage. This indicated that possibly these equations were developed primarily for the purpose of his flood-evaluation study, and in this application seepage was not important once flow into a basin ceased.

Since Carrigan's equations did not seem to work, another INEL report, a study of the 1983-1984 flood threat by J.D. McKinney (1985), was examined. In it McKinney stated that, by observation, it took one month for the spreading areas to drain once they were completely filled (McKinney, 1985, p. 6). Using this estimated time lag and the approximate volumes of the spreading areas from McKinney's report (McKinney, 1985, p B-3), seepage rates in acre-feet per month were calculated by dividing the volume of each pond by one month (31 days). Rates were then converted to cubic feet per second (cfs) per day. The seepage rates calculated for each basin were applied with the flow routing, and a set of daily seepage values for the entire period of study was then determined. It should be noted that the one month time for the basins to empty was during the summer, and therefore could have been overestimated. Because of this possibility, a sensitivity analysis on the seepage time was performed by doubling it to two months. These results will be discussed later.

Results: Spreading Areas

To perform the routing and seepage analyses for the spreading areas, a spreadsheet, QUATTRO 4.0, was used to handle all of the data. Daily inflows were obtained from the gage located near the diversion dam, at the inlet to the spreading basin system. Water was routed into the first basin until it filled, and then sequentially routed into the remaining basins. For each basin, the daily storage changes were calculated by subtracting a seepage rate from the daily inflow rate, and these storage changes then used to determine the new storage volume for that basin. This procedure was performed continuously for both periods of record (1969-76, 1983-87), with a daily seepage record tallied at the end for all the basins.

The seepage rates used in each basin were initially based on the 31-day emptying time observed by McKinney, and held constant regardless of the depth of water, or storage volume, in the basin. To test the sensitivity of the resulting total daily seepage amounts to this 31-day assumption, a second simulation was performed using a 62-day time for calculating the seepage rates for each basin. The results showed that, although the daily seepage volume was halved, the time to drain was still one month for flow events that spilled into the basins.

Concluding Remarks:

The accomplishments of the seepage estimation process included: determination of study reaches, which were a basis for the entire study; seepage equations for reaches 1 and 2 and the spreading areas (with limited applicability for those pertaining to reaches 1 and 2); and, most importantly, a daily seepage record for the entire period of study. As a final comparison for the seepage analysis, the average seepage in reaches 1 and 2 and the spreading areas for the entire study period are listed below for comparison.

Average seepage in reach 1 = 782.3 cfs
Average seepage in reach 2 = 574.7 cfs
Average seepage in spreading areas = 3688.5 cfs

The importance of these differences in seepage will be seen in the impact on the groundwater, and therefore the next analysis, seepage versus groundwater levels.

CHAPTER V

Seepage-Groundwater Correlation

OVERVIEW

Seepage or recharge from the Big Lost River does not directly affect all facilities on the INEL site because some are located too far from the river. However, areas near the river channel or spreading basins may experience temporary saturation of the underlying porous media, including localized groundwater mounding. As has already been discussed, radioactive and other wastes have been allowed to infiltrate into the Snake River Plain aquifer through percolation ponds at the TRA and other sites. Also, some very high level waste is buried at the RWMC. If any of these contaminants are migrating through the unsaturated zone and into the aquifer, any significant changes in groundwater levels or the saturated zones could alter the concentration, path, and timing of the transport process. For this reason, a clear understanding of the relationship between seepage and groundwater response is essential.

Therefore, the ultimate objective of this study was to examine the time series of both seepage and groundwater levels near the river, and to determine whether a consistent relationship exists between the two time series. It was hypothesized that if groundwater levels directly responded to changes in seepage rates, there would be a time lag evident in this response. Such a lag, if it could be identified and quantified, would provide a clue to the migration time of surface water through the unsaturated zone and into the aquifer

APPROACH

To initiate this part of the study, wells and their locations on the site first had to be identified and researched to determine which to use in examining the seepage-groundwater relationship. Maps of well locations on the INEL site were obtained, and from a review of these maps a number of potential candidate wells were selected. Although the maps indicated both private and USGS wells, it was decided, for several reasons, to work only with USGS well data. The data from most of the private wells are proprietary, and therefore may have been difficult to obtain without a lengthy permission process. On the other hand, the USGS well data are in the public domain, the wells are in excellent locations near the study reaches, and their descriptions and behavior have been well-documented in a variety of USGS site-hydrology reports.

This prior hydrologic research performed by the USGS was carefully reviewed. Many reports included brief sections that discussed various USGS wells and their response to flows in the river, with an identification of those wells that appeared to respond most dramatically to changes in flow. Bennett (1990) included in his report a discussion about USGS wells and compared hydrographs with flow in the river. Earlier USGS hydrology reports did the same. An inventory of wells used in these reports was compiled and compared against the initial, more comprehensive list of wells. Many of the wells initially chosen were geographically grouped together and at most only one per group was necessary for the study. Wells located in close proximity to the river and spreading areas were considered most important because of their prime location.

From all of these evaluations, a list of the most responsive wells was assembled, and it was then finally narrowed down to the choices of USGS wells 8, 9 and 18. USGS 8 is located just outside the western boundary of the site and near the Arco river gage. It provided a good location for correlation with seepage in reach one. USGS 9 is located near the spreading areas and provided information for groundwater beneath the RWMC. USGS 18 is located in the northern portion of the site and was compared against seepage from reach three. All water level data available from these wells were entered into a QUATTRO spreadsheet for use in the correlation analysis.

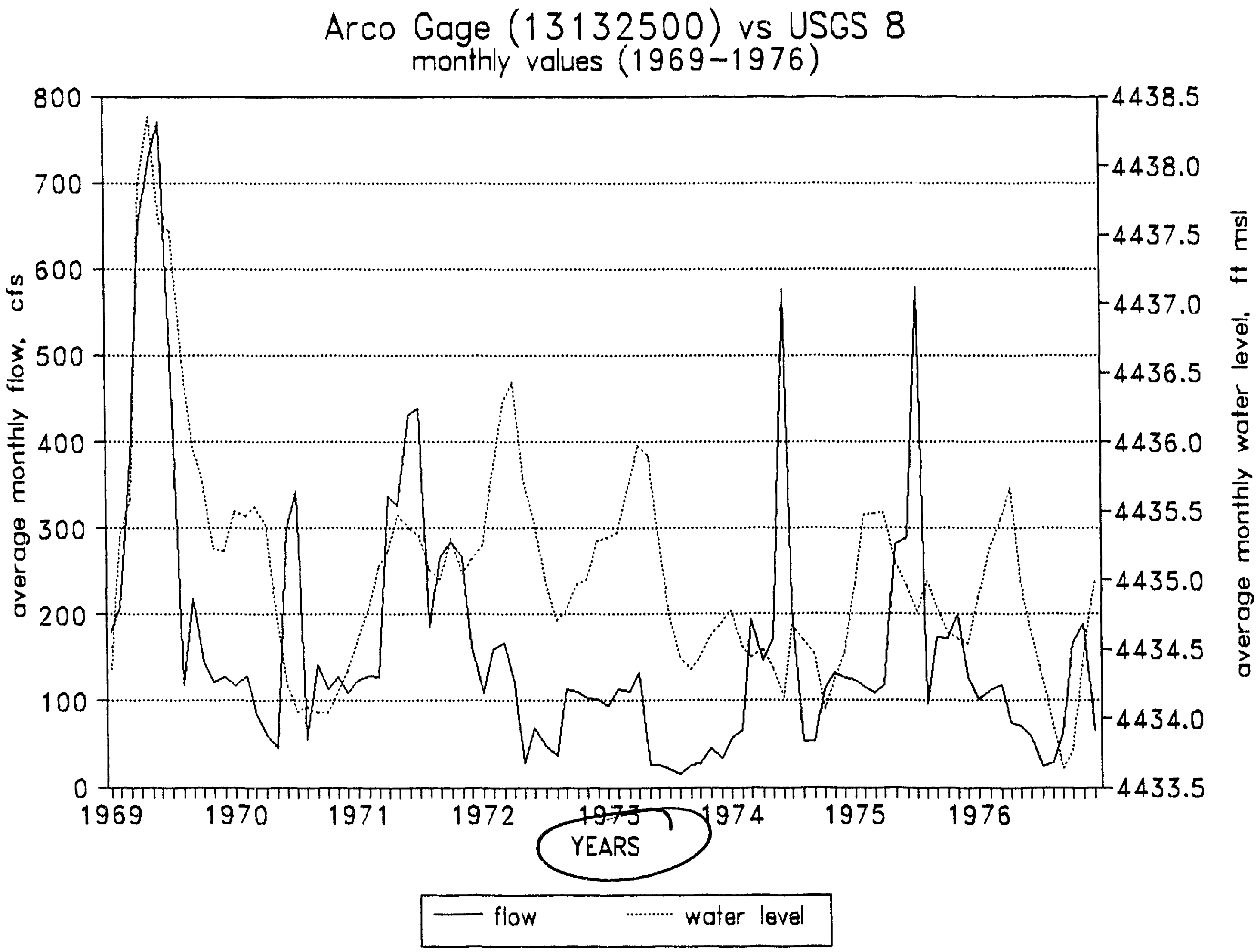
Flow and Water Levels

To begin the correlation analysis, a broad approach was initially taken by simply comparing flows in the river with groundwater levels in the selected wells. This exercise was performed to determine if any correlation appeared to exist with these wells before too much time was spent in detailed comparisons of seepage and groundwater levels.

A consistent time basis was necessary to compare well hydrographs with gage hydrographs. All the river gages were monitored on a continuous basis, but the same was not true for the wells. Water levels were checked sporadically, most often once or twice a month. Therefore, average monthly water levels were compared to average monthly flows. To obtain averages for the wells, all measurements taken each month were averaged to obtained monthly water levels. Average monthly flows were simply the means of the daily flows for the entire month.

In the analysis, well hydrographs were first graphically, then mathematically, compared against flow hydrographs in different reaches, depending on the well locations with respect to reaches. USGS 8 records were compared against both the gages at Arco (gage 13132500) and above the diversion dam (synthesized gage 13132510); USGS 9 was compared against the flows above the diversion dam and at Lincoln boulevard (gage 13132535), and USGS 18 was compared against the gage at Lincoln boulevard. These graphs are presented in figures 5.1 through 5.10. As is illustrated with these graphs, the most notable fact is that a time lag appears to exist, with groundwater levels responding consistently after significant flow events.

To study this apparent time lag phenomenon further, the hydrographs were first smoothed to be more readable and easier to compare. One statistical procedure to do this is termed "moving average", and is often used to reduce short-term variability of data to more easily detect underlying longer-term trends. A moving average is established by first taking an average over a sequential set of numbers, X, of a total data set, Y, beginning with the first number, i. Then another average is taken over the



Arco Gage (13132500) vs USGS 8
monthly values (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
0
100
200
300
400
500
600
700
800
4433.5
4434.0
4434.5
4435.0
4435.5
4436.0
4436.5
4437.0
4437.5
4438.0
4438.5
1969
1970
1971
1972
1973
1974
1975
1976
YEARS
flow
water level

fig 5.1

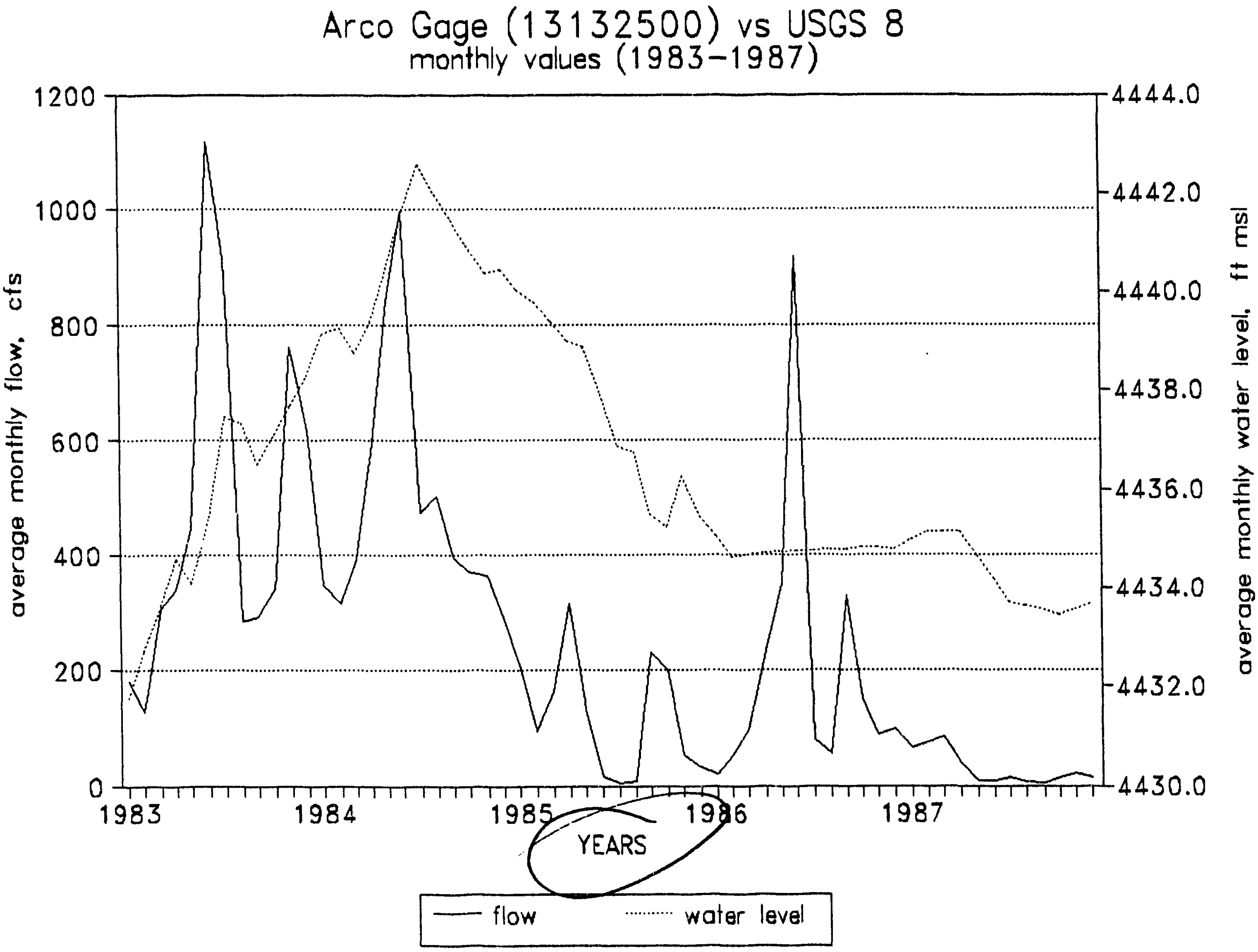
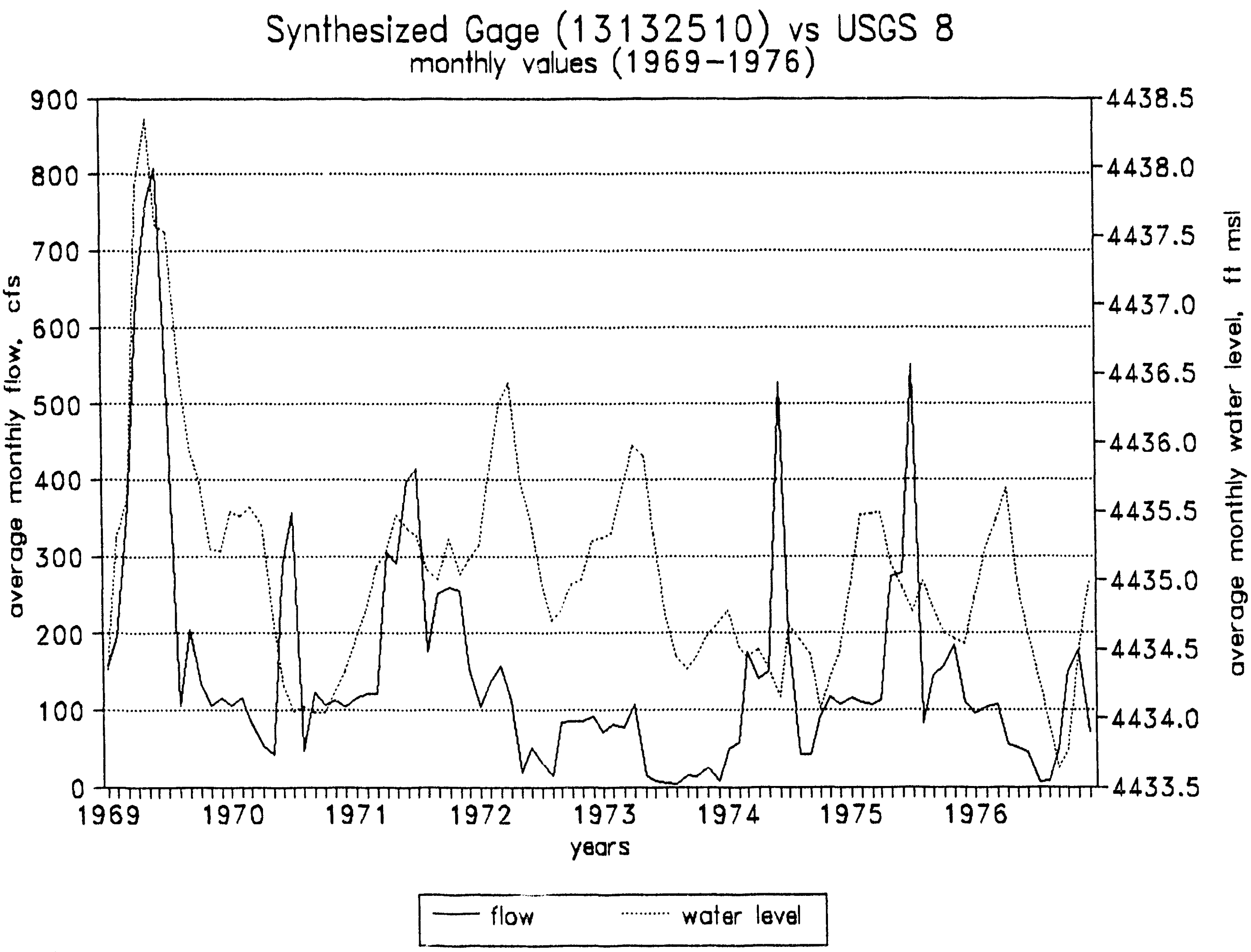
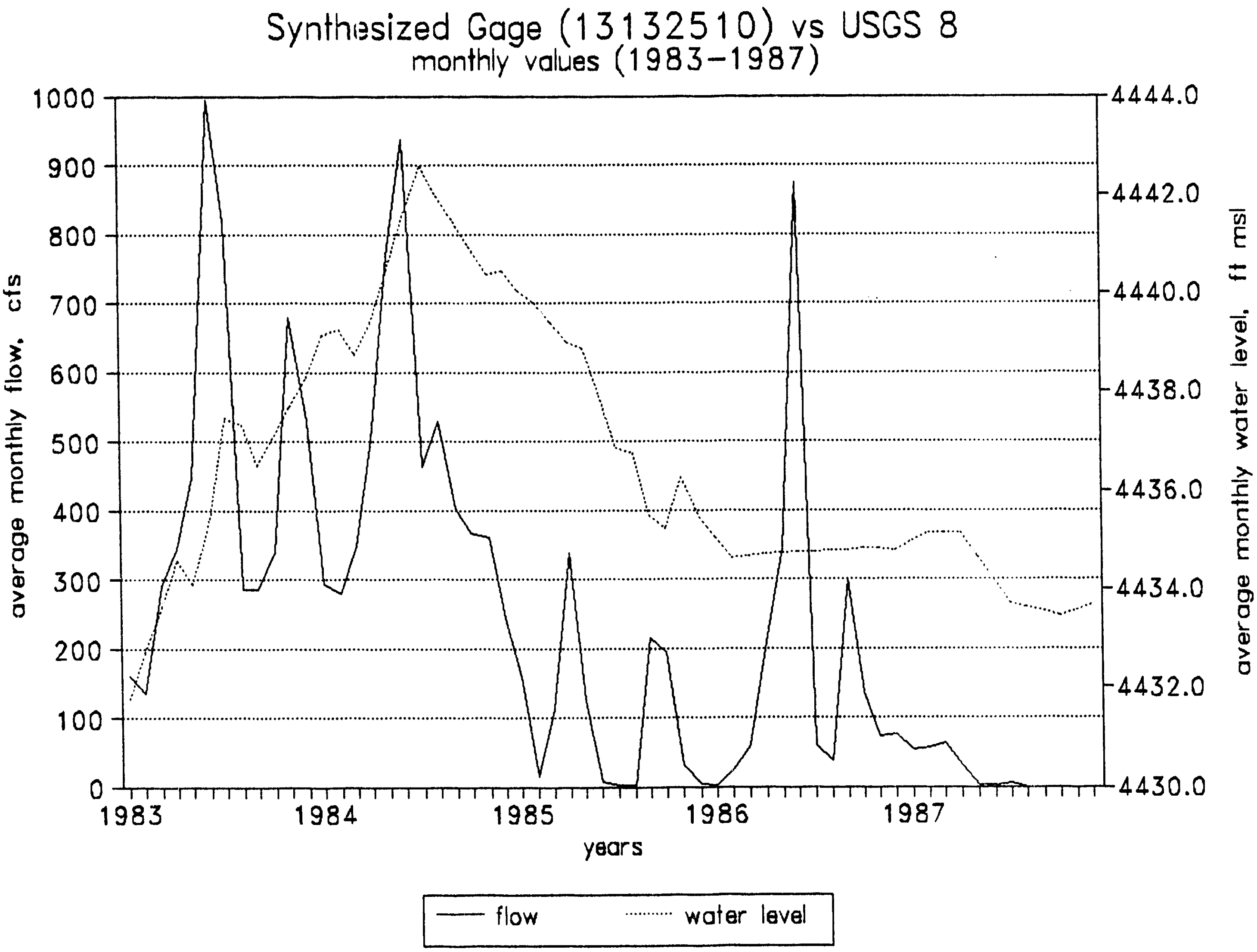

Arco Gage (13132500) vs USGS 8
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
1200
1000
800
600
400
200
0
4444.0
4442.0
4440.0
4438.0
4436.0
4434.0
4432.0
4430.0
1983
1984
1985
1986
1987
YEARS
flow
water level

fig 5.2



Synthesized Gage (13132510) vs USGS 8
monthly values (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
900
800
700
600
500
400
300
200
100
0
4438.5
4438.0
4437.5
4437.0
4436.5
4436.0
4435.5
4435.0
4434.5
4434.0
4433.5
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

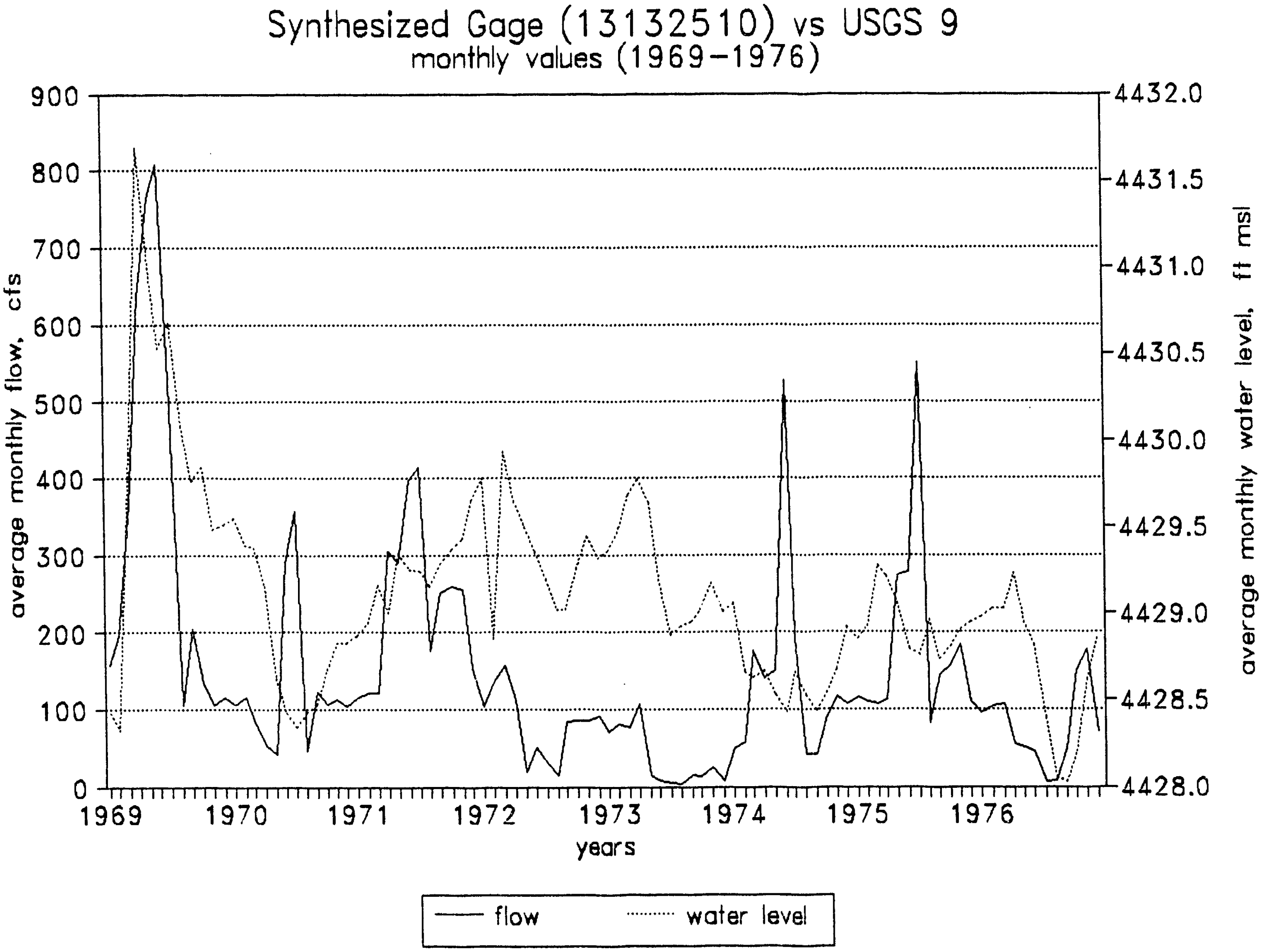
fig 5.3



Synthesized Gage (13132510) vs USGS 8
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
years
1983
1984
1985
1986
1987
0
100
200
300
400
500
600
700
800
900
1000
4430.0
4432.0
4434.0
4436.0
4438.0
4440.0
4442.0
4444.0
flow
water level

fig 5.4

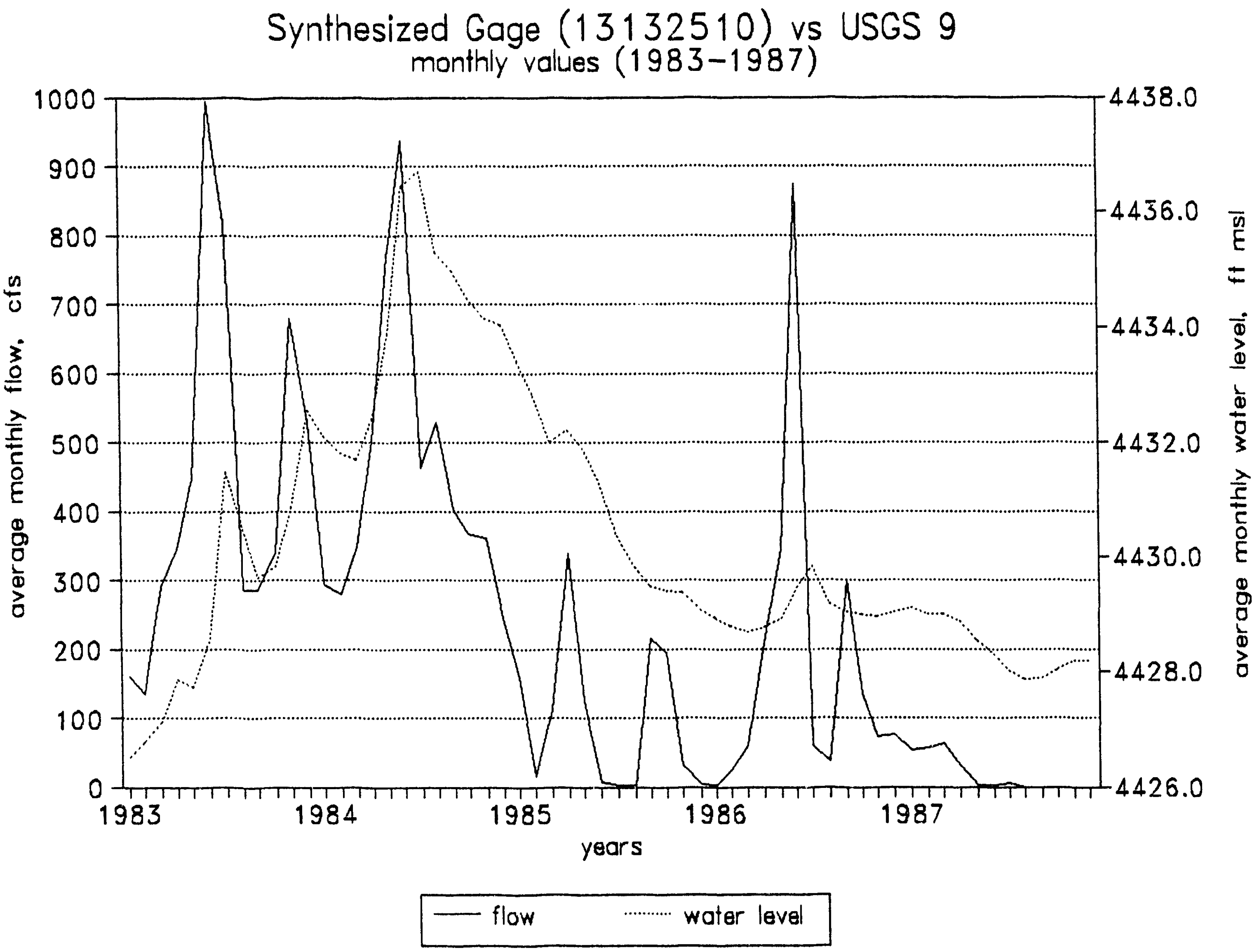
7.



Synthesized Gage (13132510) vs USGS 9
monthly values (1969–1976)
average monthly flow, cfs
average monthly water level, ft msl
900
800
700
600
500
400
300
200
100
0
4432.0
4431.5
4431.0
4430.5
4430.0
4429.5
4429.0
4428.5
4428.0
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

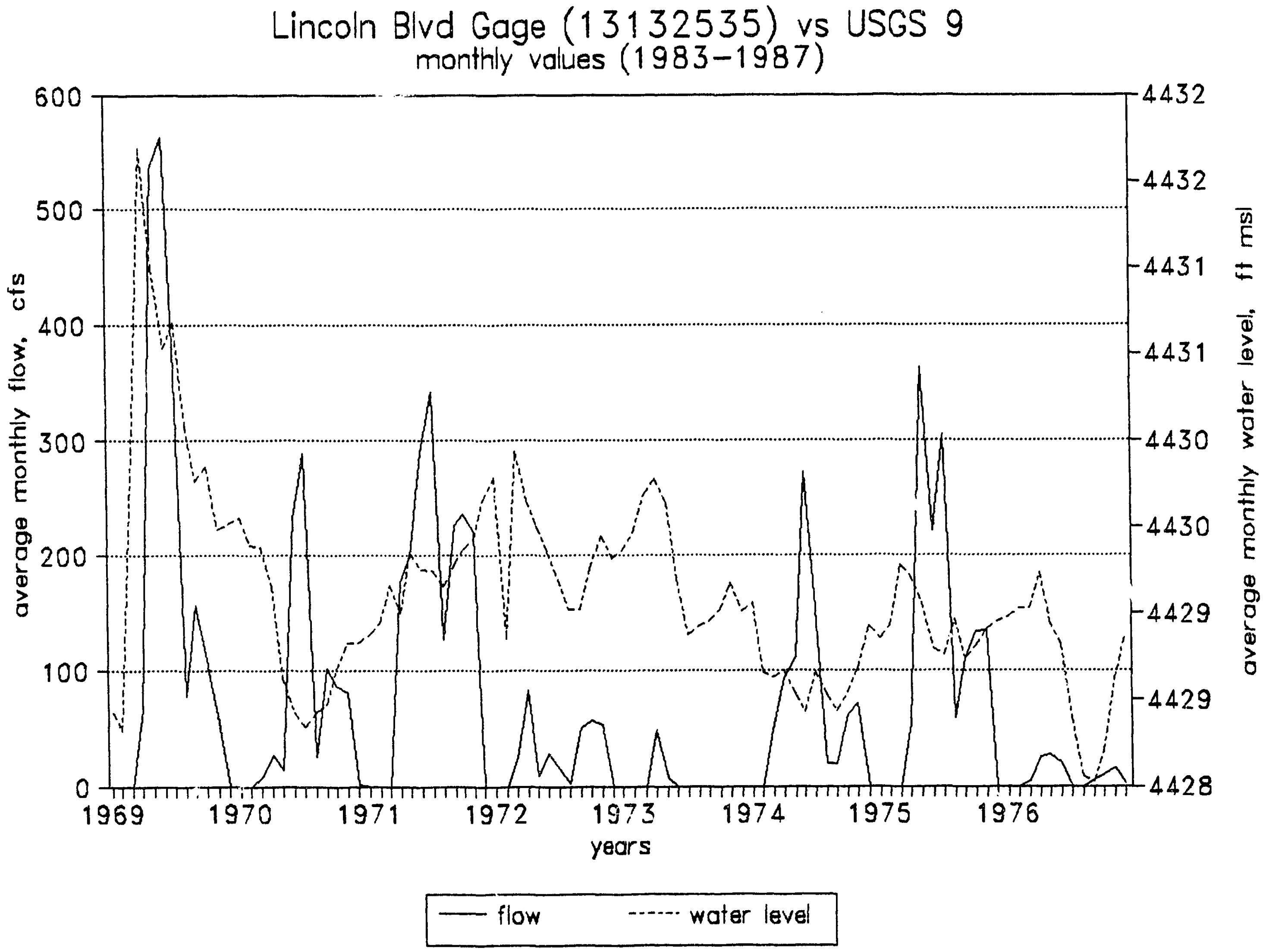
fig 5.5

8.



Synthesized Gage (13132510) vs USGS 9
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
1000
900
800
700
600
500
400
300
200
100
0
4438.0
4436.0
4434.0
4432.0
4430.0
4428.0
4426.0
1983
1984
1985
1986
1987
years
flow
water level

fig 5.6



Lincoln Blvd Gage (13132535) vs USGS 9
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
0
100
200
300
400
500
600
4428
4429
4429
4430
4430
4431
4431
4432
4432
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

fig 5.7

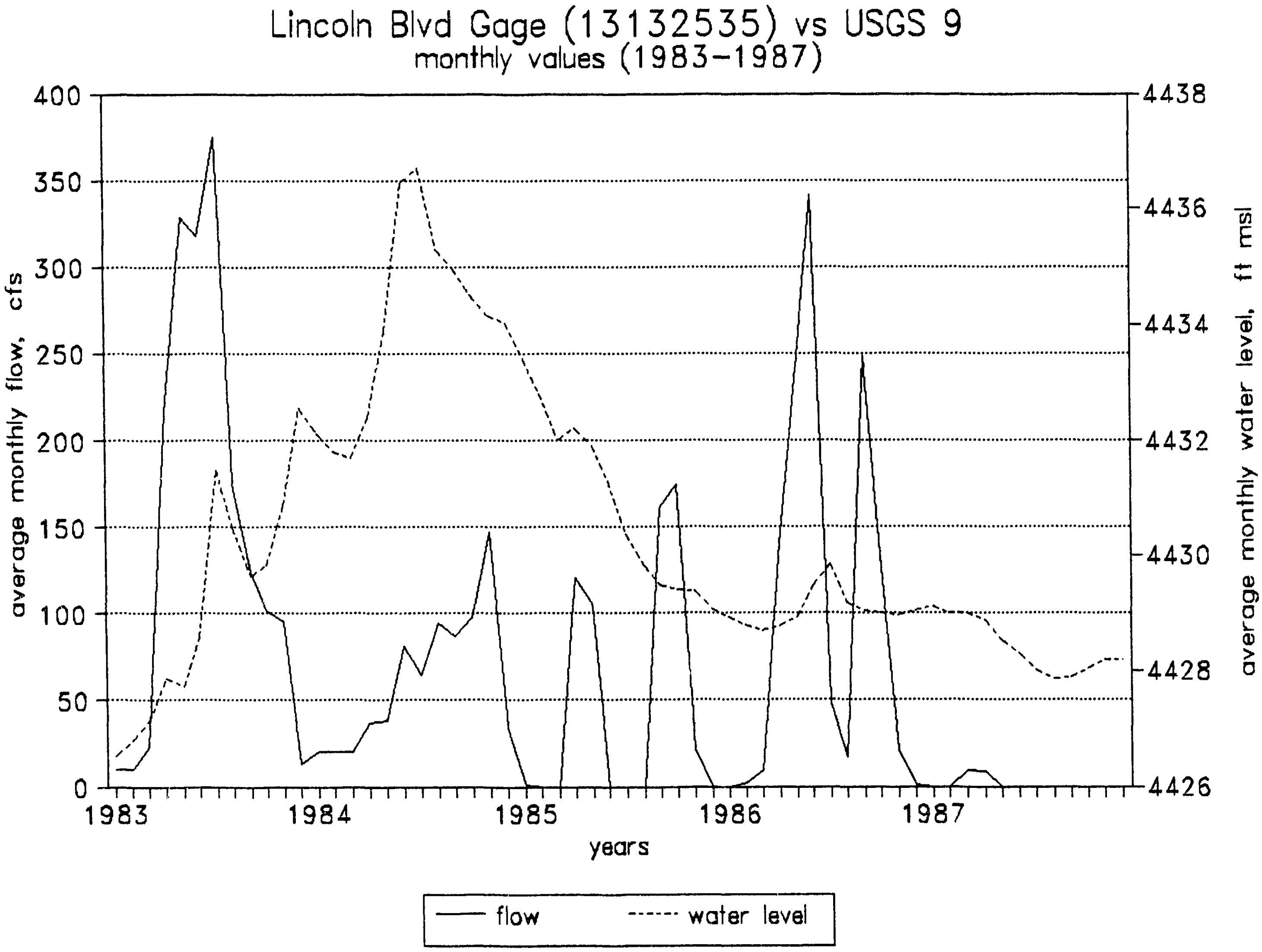
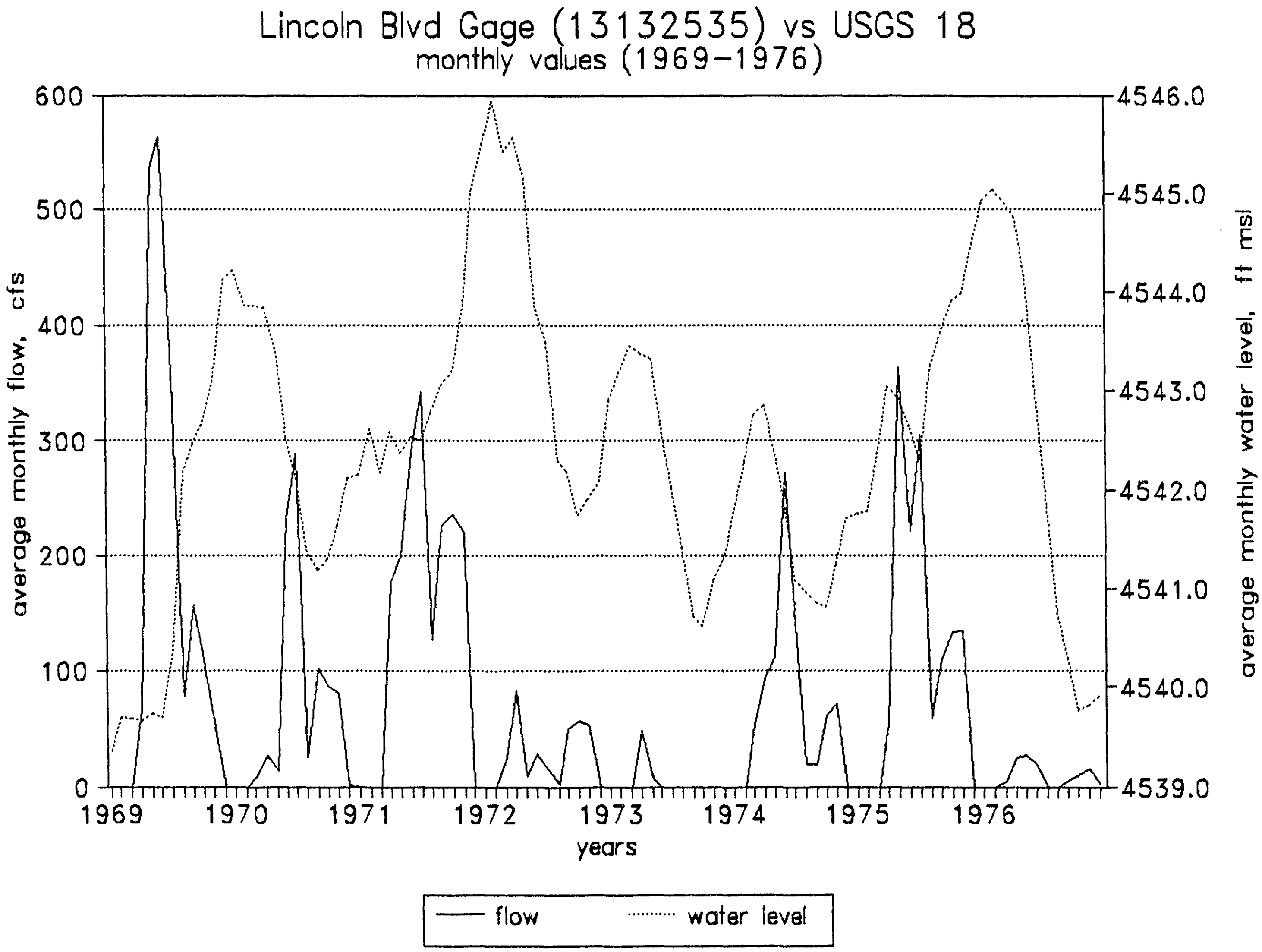

Lincoln Blvd Gage (13132535) vs USGS 9
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
0
50
100
150
200
250
300
350
400
4426
4428
4430
4432
4434
4436
4438
1983
1984
1985
1986
1987
years
flow
water level

fig 5.8

9.



Lincoln Blvd Gage (13132535) vs USGS 18
monthly values (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
600
500
400
300
200
100
0
4546.0
4545.0
4544.0
4543.0
4542.0
4541.0
4540.0
4539.0
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

fig 5.9

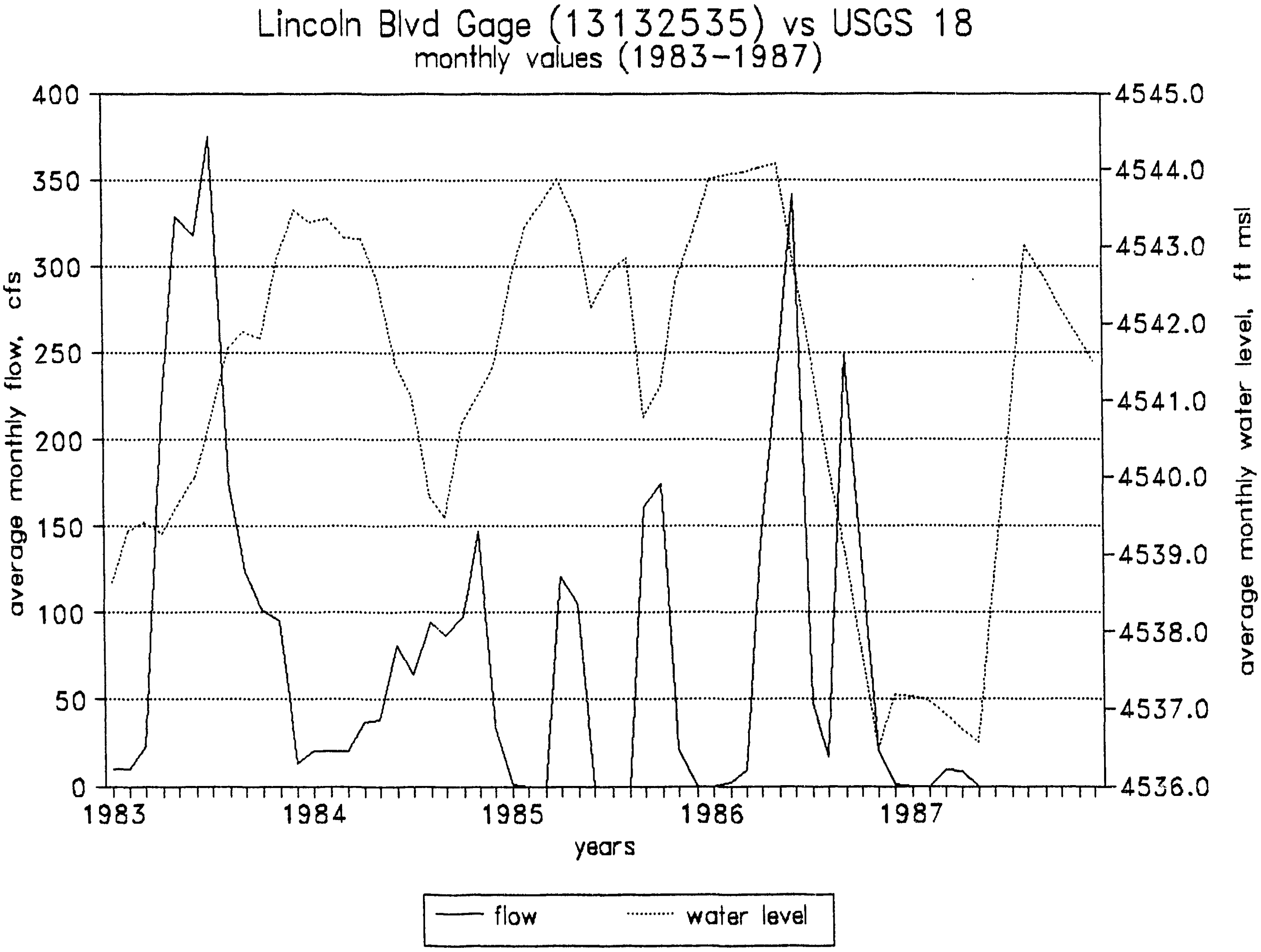

Lincoln Blvd Gage (13132535) vs USGS 18
monthly values (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
400
350
300
250
200
150
100
50
0
4545.0
4544.0
4543.0
4542.0
4541.0
4540.0
4539.0
4538.0
4537.0
4536.0
1983
1984
1985
1986
1987
years
flow
water level

fig 5.10

same amount of numbers, X, but beginning at i+1. It ends when the moving average includes the last number of the total data set, Y. In this case the moving average was over a period of time (ie: months, years).

A number of different time period moving averages, starting at two months, were examined and it was eventually concluded that a moving average based on a 12-month period provided the best smoothed representation of the data sets. This was obtained by taking the average of water levels and flows from January to December, then February to January, March to February, etc., until the entire periods of record (1969-76 and 1983-87) had been averaged.

Obviously, this averaging process causes significant distortion to the time series by including future as well as prior values in the calculation of each point. However, since the two time series (flow and groundwater levels) are both averaged in the same way, these distortions do not adversely affect the comparisons that can be made between them. At this point in the study, the primary objective was simply to determine whether, visually, there appeared to be a consistent relationship between streamflow and groundwater levels. If so, a more detailed evaluation of the seepage-groundwater relationship is indicated.

After performing the necessary calculations, the 12-month moving averages of flow and groundwater levels were plotted, and can be seen in figures 5.11 through 5.20. An examination of these graphs demonstrates that there is an obvious time lag relationship between flows in the river and groundwater levels in the selected wells. By visual inspection of these figures, it appears that this time lag is between four and seven months. This first approach therefore confirms that the wells chosen were hydrologically connected to the river and that a time-lagged correlation did exist between flow rates and groundwater levels.

Seepage and Water Levels

The final step in the study was to compare total monthly seepage with average monthly groundwater levels, since it is the seepage, not flow, that impacts the groundwater in a cause-effect relationship. In these analyses, seepage from reach one was compared against water levels in USGS 8, seepage from the spreading areas and reach two were compared against USGS 9, seepage from reach three was compared against USGS 18, and the combined seepage from reach one and the spreading areas was compared against USGS 9. Again it was analyzed on a monthly basis, using total monthly seepage and average monthly water levels. Hydrographs were graphed together for comparison, with seepage and water levels on the y-axis and time on the x-axis.

REACH 1 AND USGS 8

Figures 5.21 and 5.22 show the plots of total monthly seepage and average monthly water levels against time, for the two separate time periods (1969-76 and 1983-87). It was noted that the graphs displayed considerable short-term variability, indicating that a moving average may be beneficial in comparing

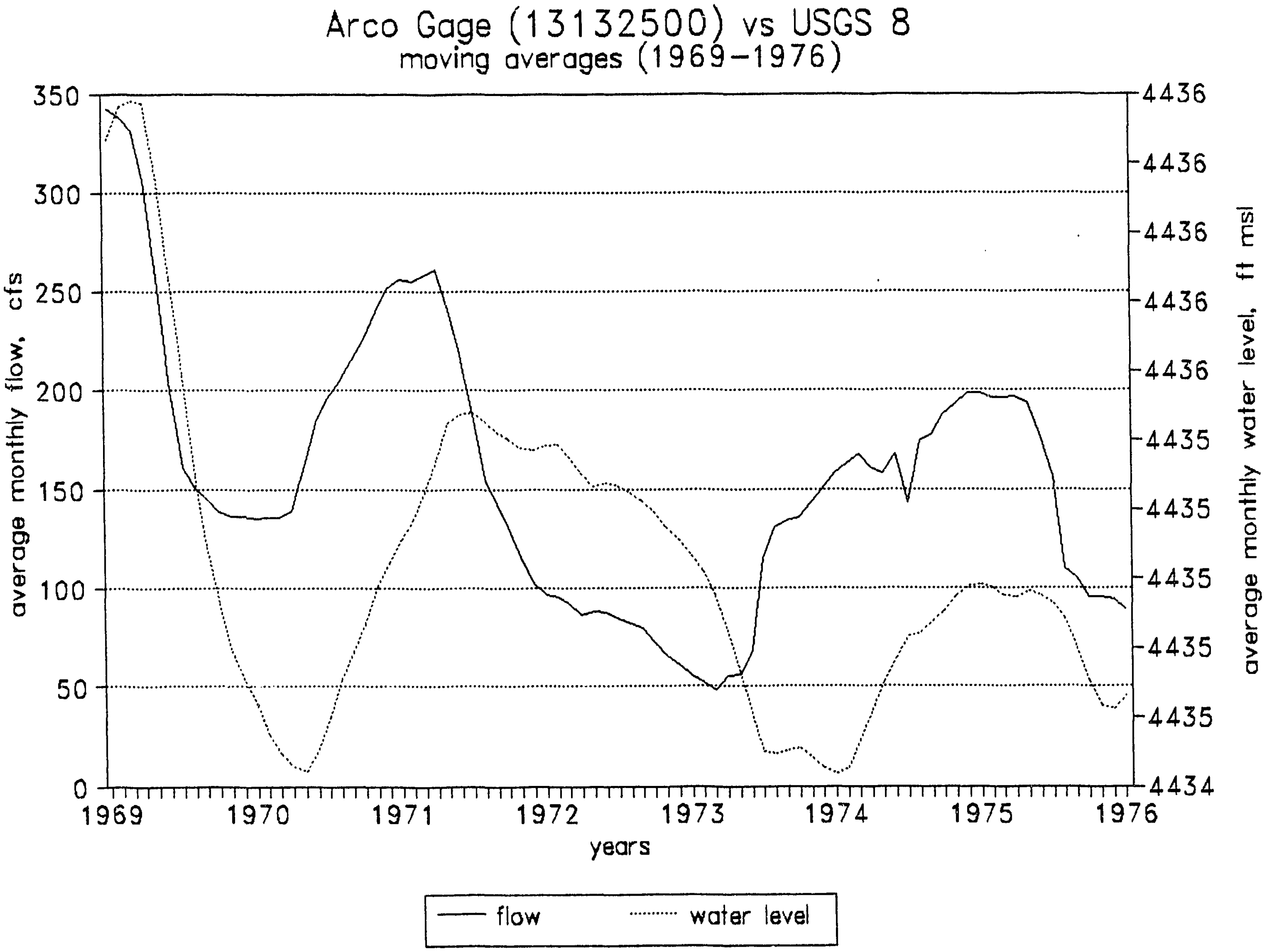
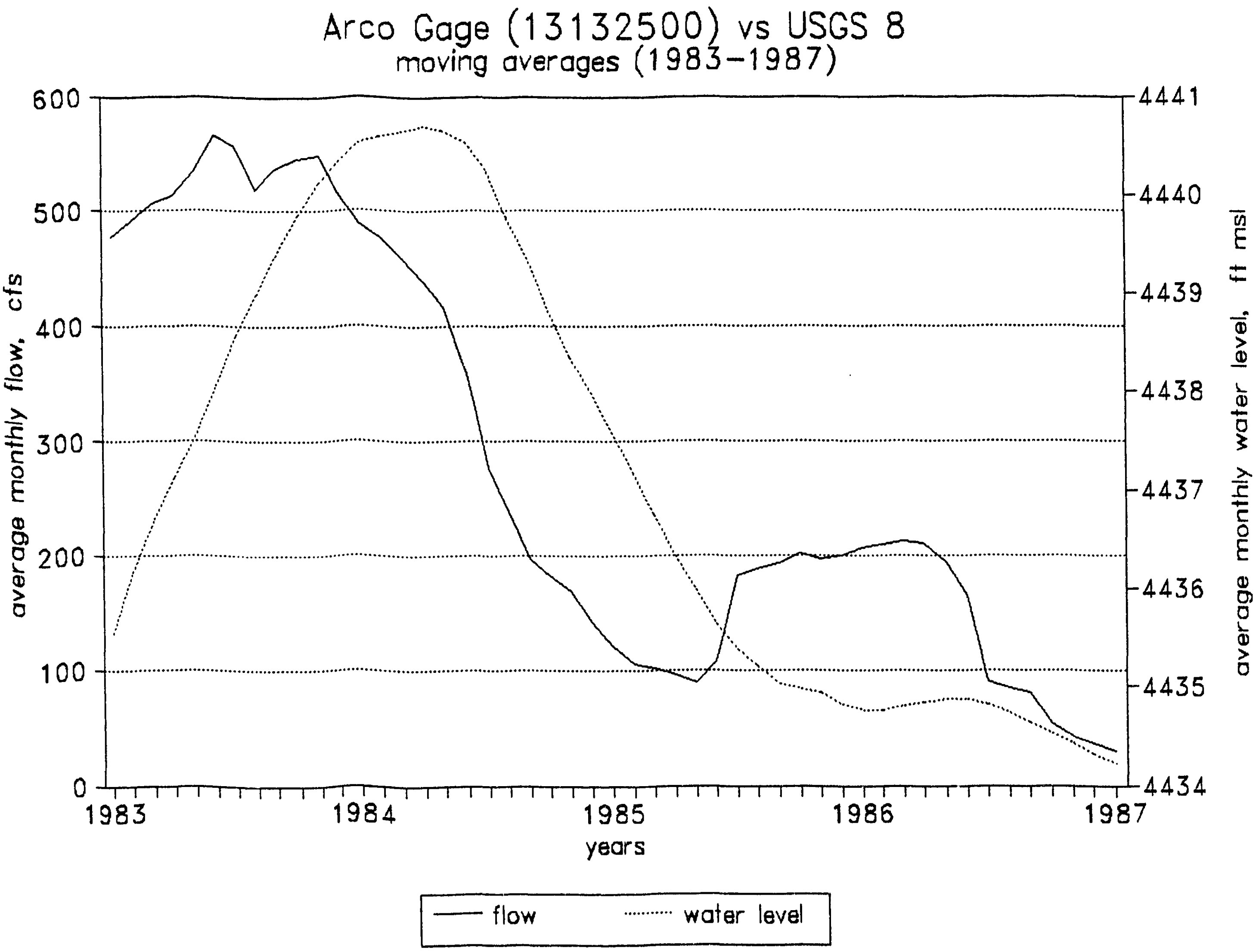

Arco Gage (13132500) vs USGS 8
moving averages (1969-1976)
350
300
250
200
150
100
50
0
4436
4436
4436
4436
4436
4435
4435
4435
4435
4435
4434
1969
1970
1971
1972
1973
1974
1975
1976
years
average monthly flow, cfs
average monthly water level, ft msl
flow
water level

fig 5.11



Arco Gage (13132500) vs USGS 8
moving averages (1983–1987)
average monthly flow, cfs
average monthly water level, ft msl
600
500
400
300
200
100
0
4441
4440
4439
4438
4437
4436
4435
4434
1983
1984
1985
1986
1987
years
flow
water level

fig 5.12

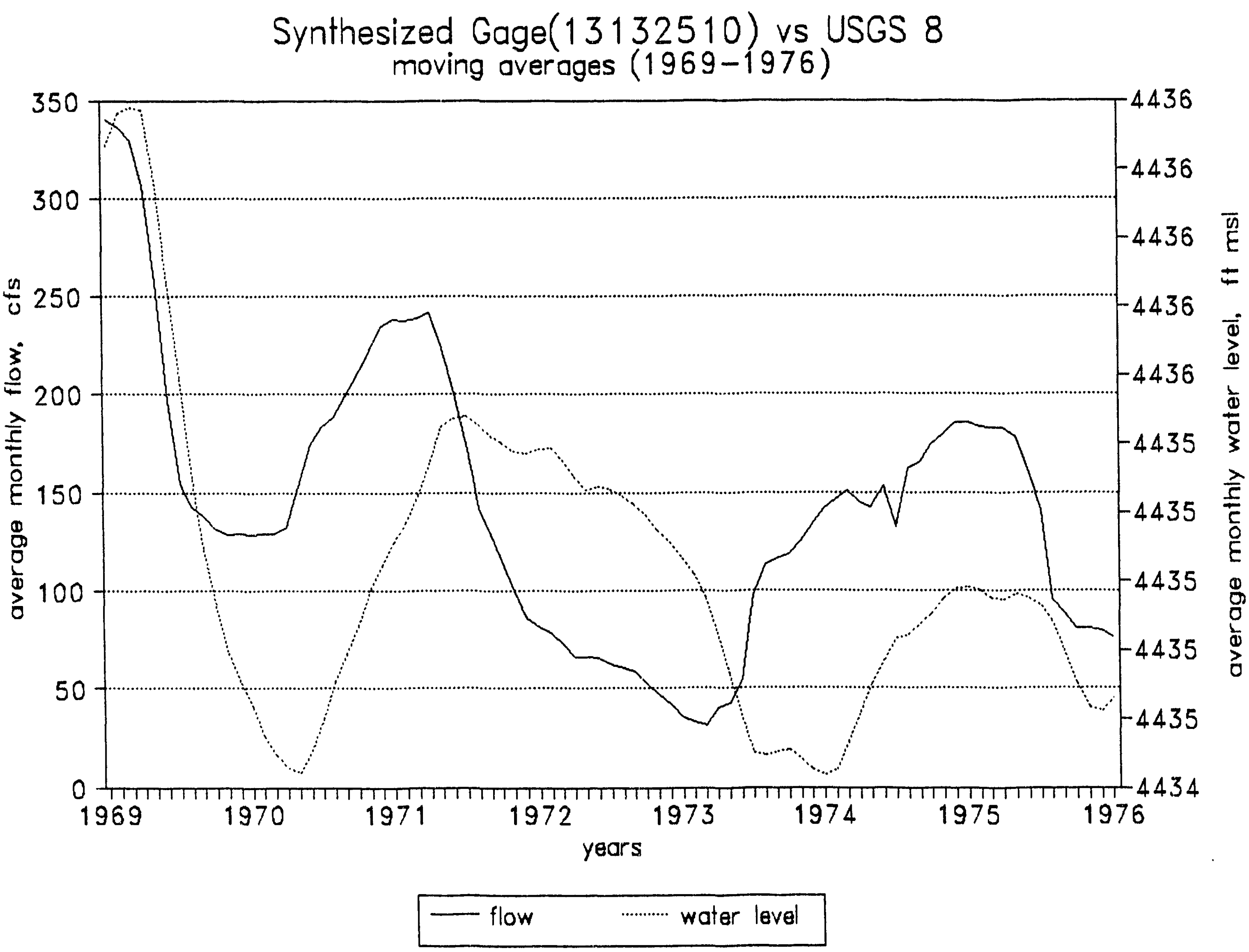

Synthesized Gage(13132510) vs USGS 8
moving averages (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
350
300
250
200
150
100
50
0
4436
4436
4436
4436
4436
4435
4435
4435
4435
4435
4434
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

fig 5.13

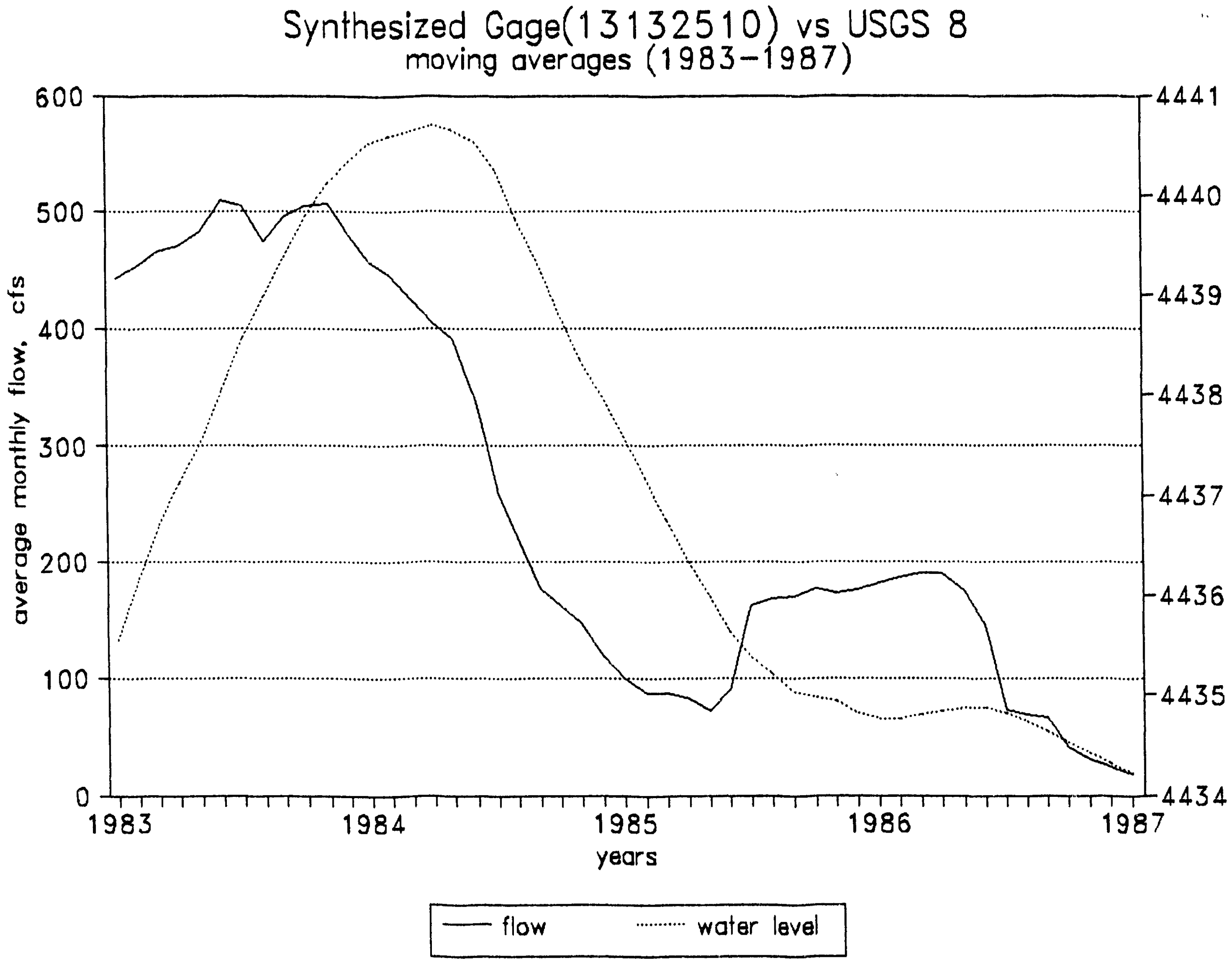

Synthesized Gage(13132510) vs USGS 8
moving averages (1983-1987)
600
500
400
300
200
100
0
average monthly flow, cfs
4441
4440
4439
4438
4437
4436
4435
4434
average monthly water level, ft msl
1983
1984
1985
1986
1987
years
flow
water level

fig 5.14

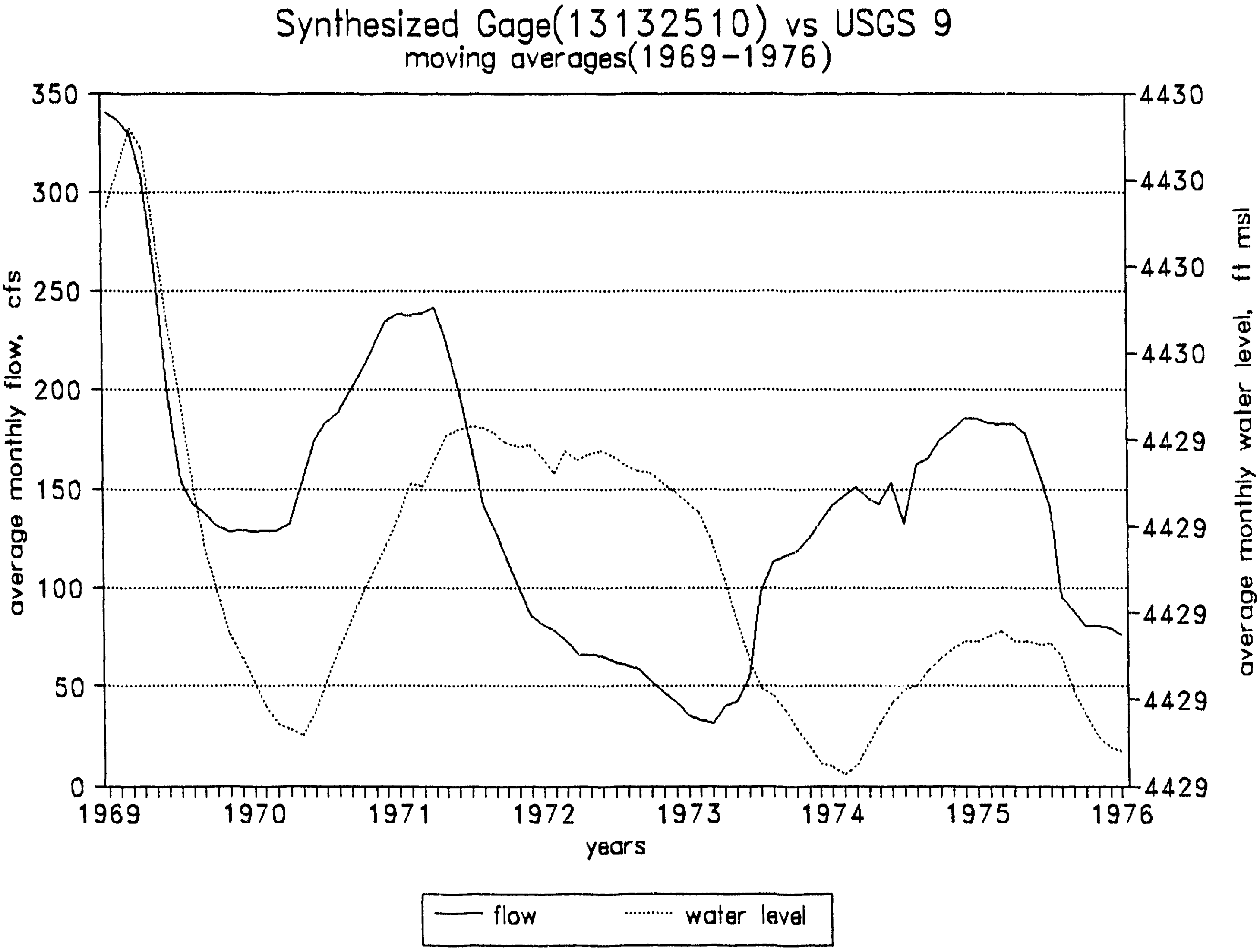

Synthesized Gage(13132510) vs USGS 9
moving averages(1969-1976)
350
300
250
200
150
100
50
0
average monthly flow, cfs
4430
4430
4430
4430
4429
4429
4429
4429
4429
average monthly water level, ft msl
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

fig 5.15

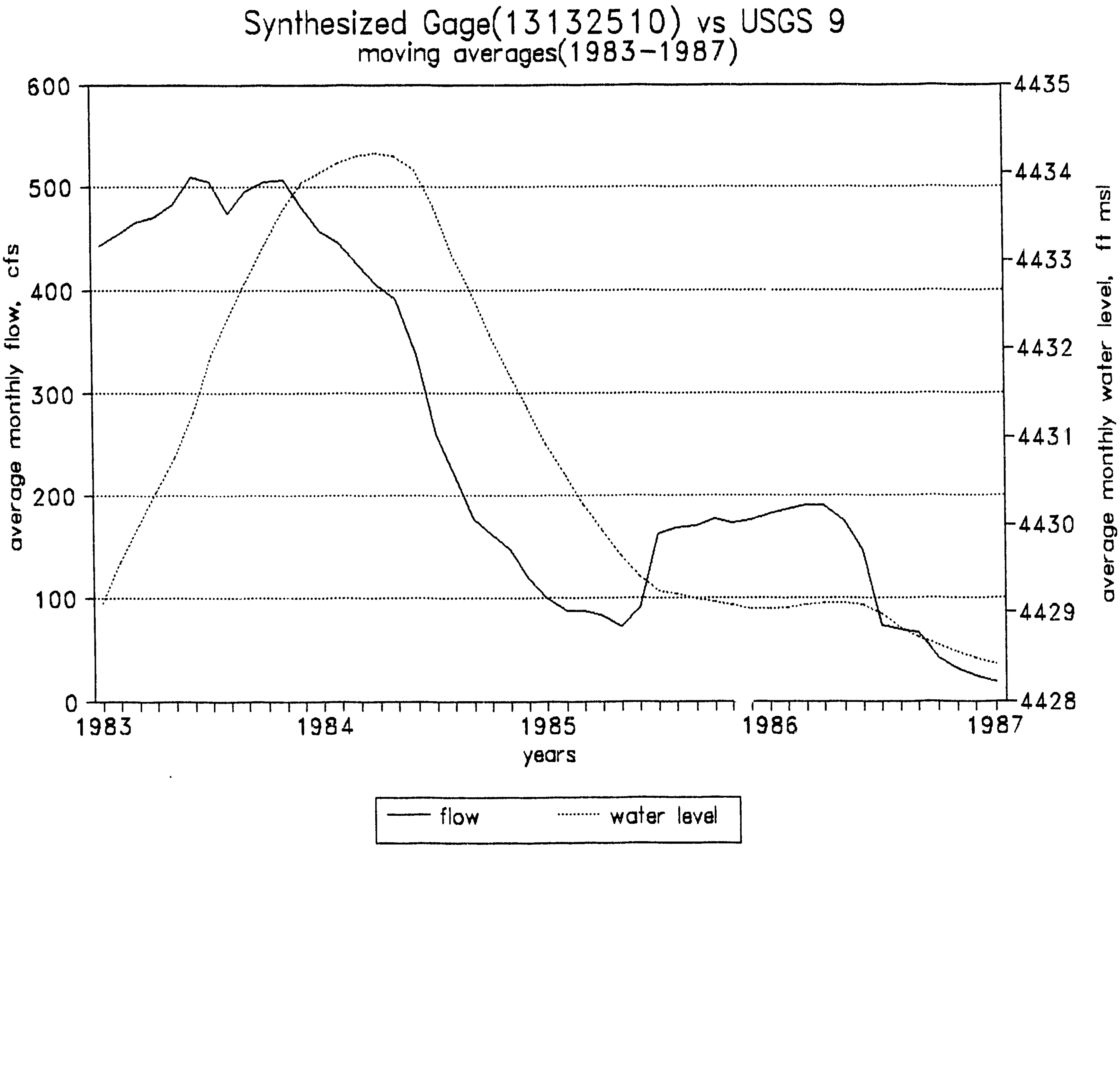
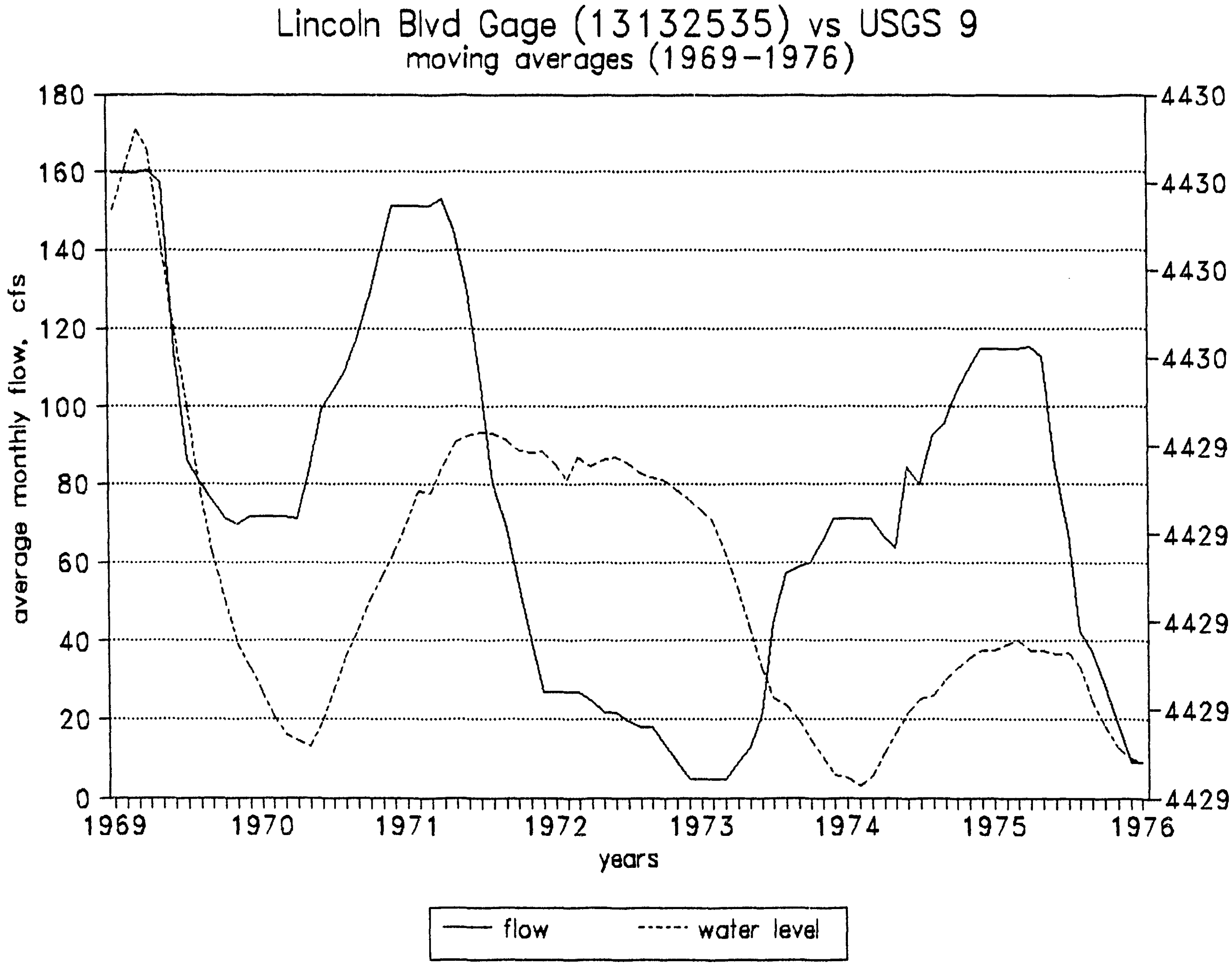

Synthesized Gage(13132510) vs USGS 9
moving averages(1983-1987)
600
500
400
300
200
100
0
4435
4434
4433
4432
4431
4430
4429
4428
average monthly flow, cfs
average monthly water level, ft msl
1983
1984
1985
1986
1987
years
flow
water level

fig 5.16



Lincoln Blvd Gage (13132535) vs USGS 9
moving averages (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
180
160
140
120
100
80
60
40
20
0
4430
4430
4430
4430
4429
4429
4429
4429
4429
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

Fig 5.17

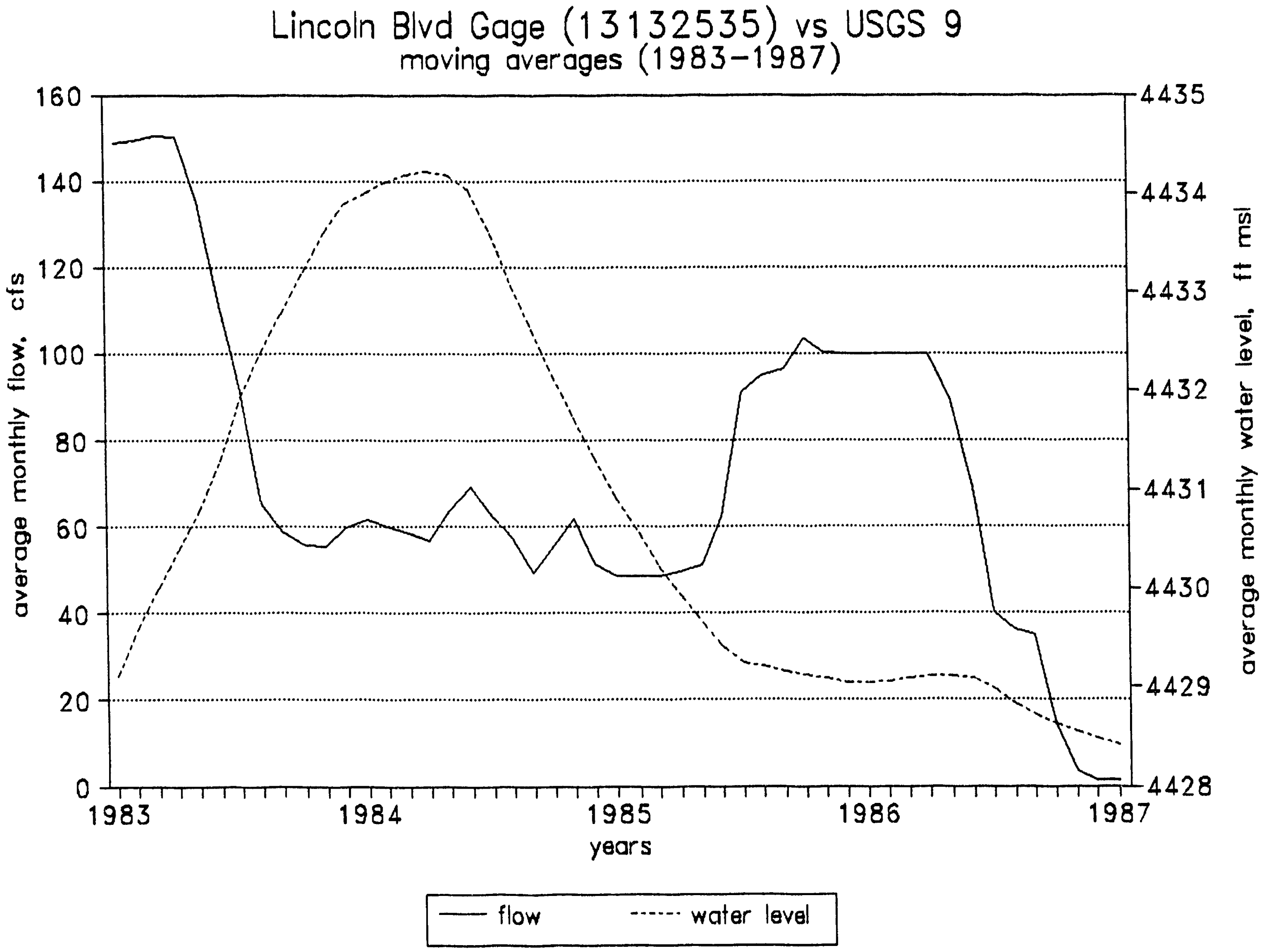
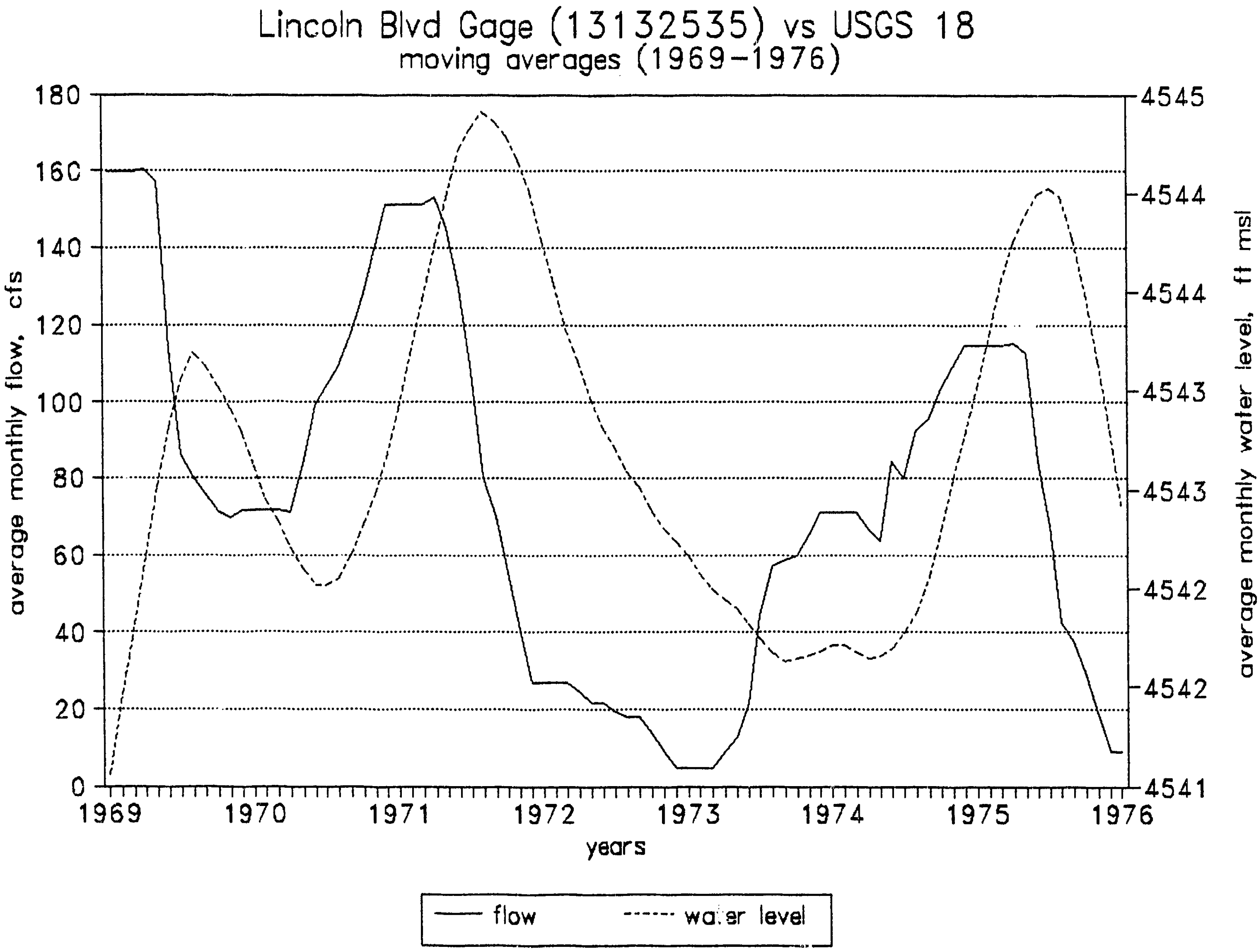

Lincoln Blvd Gage (13132535) vs USGS 9
moving averages (1983-1987)
average monthly flow, cfs
average monthly water level, ft msl
160
140
120
100
80
60
40
20
0
4435
4434
4433
4432
4431
4430
4429
4428
1983
1984
1985
1986
1987
years
flow
water level

Fig 5.18



Lincoln Blvd Gage (13132535) vs USGS 18
moving averages (1969-1976)
average monthly flow, cfs
average monthly water level, ft msl
0
20
40
60
80
100
120
140
160
180
4541
4542
4542
4542
4543
4543
4544
4544
4544
4545
1969
1970
1971
1972
1973
1974
1975
1976
years
flow
water level

fig 5.19

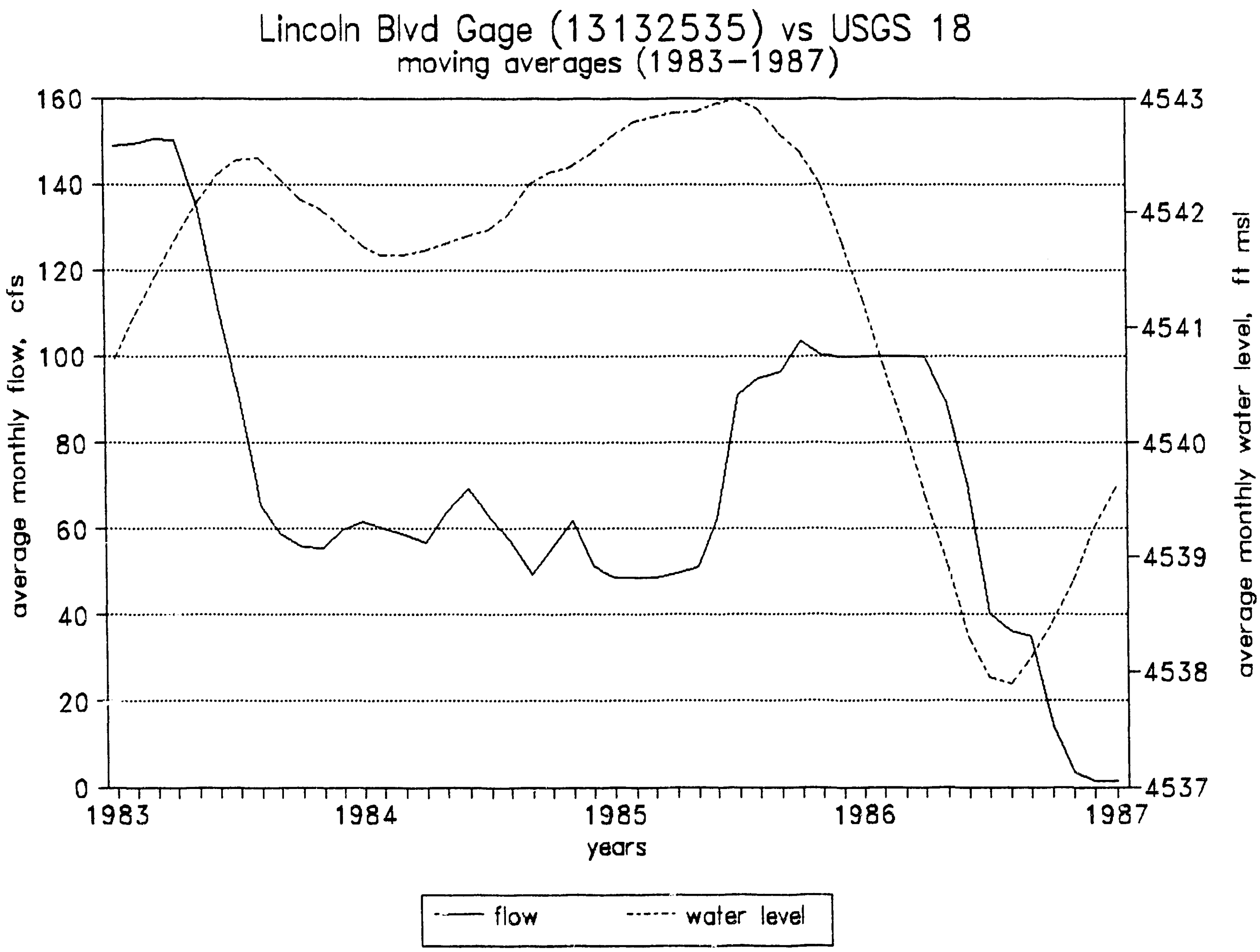

Lincoln Blvd Gage (13132535) vs USGS 18
moving averages (1983-1987)
160
140
120
100
80
60
40
20
0
average monthly flow, cfs
4543
4542
4541
4540
4539
4538
4537
average monthly water level, ft msl
1983
1984
1985
1986
1987
years
flow
water level

fig 5.20

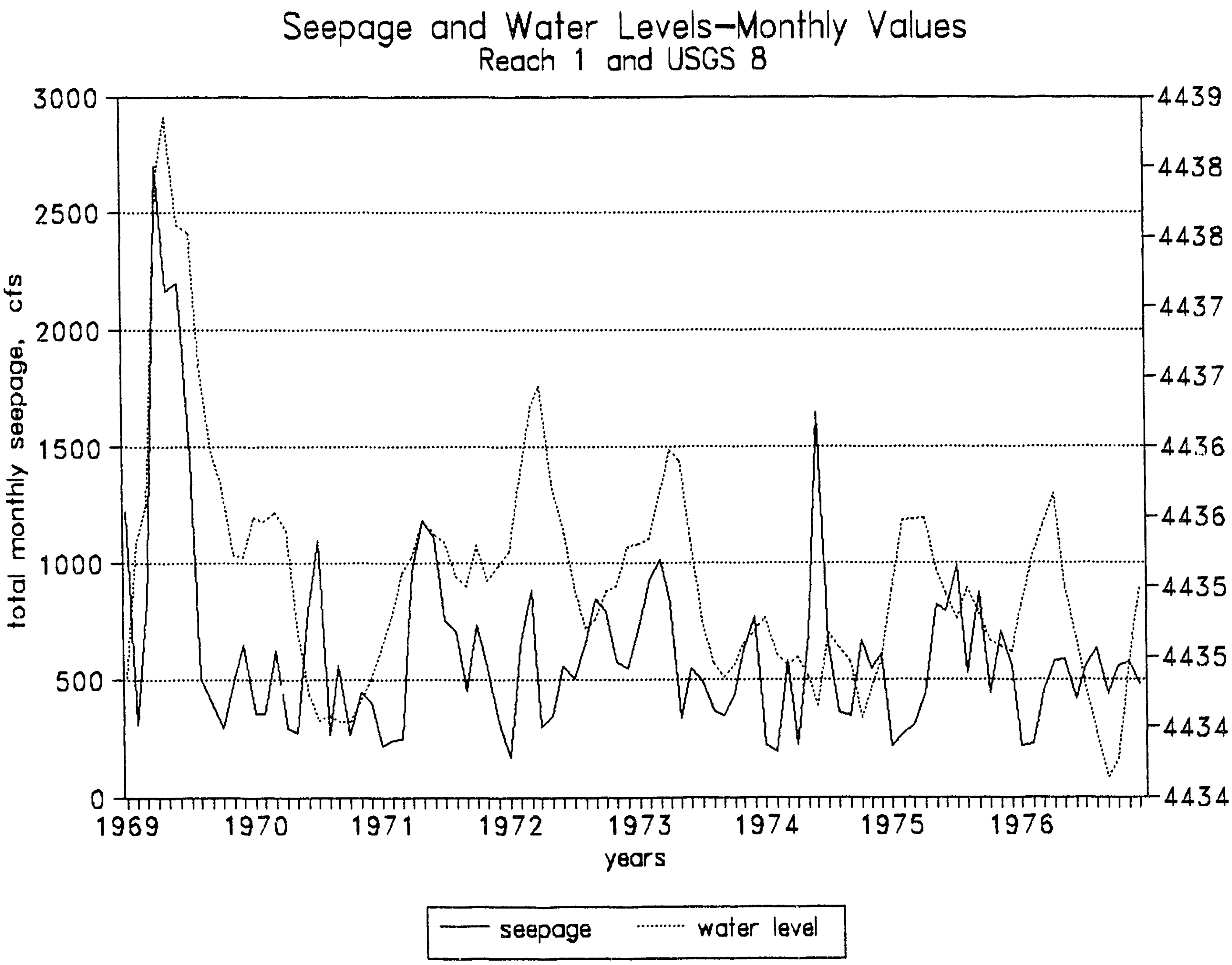

Seepage and Water Levels—Monthly Values
Reach 1 and USGS 8
3000
2500
2000
1500
1000
500
0
total monthly seepage, cfs
4439
4438
4438
4437
4437
4436
4436
4435
4435
4434
4434
average monthly water level, ft msl
1969
1970
1971
1972
1973
1974
1975
1976
years
seepage
water level

fig 5.21

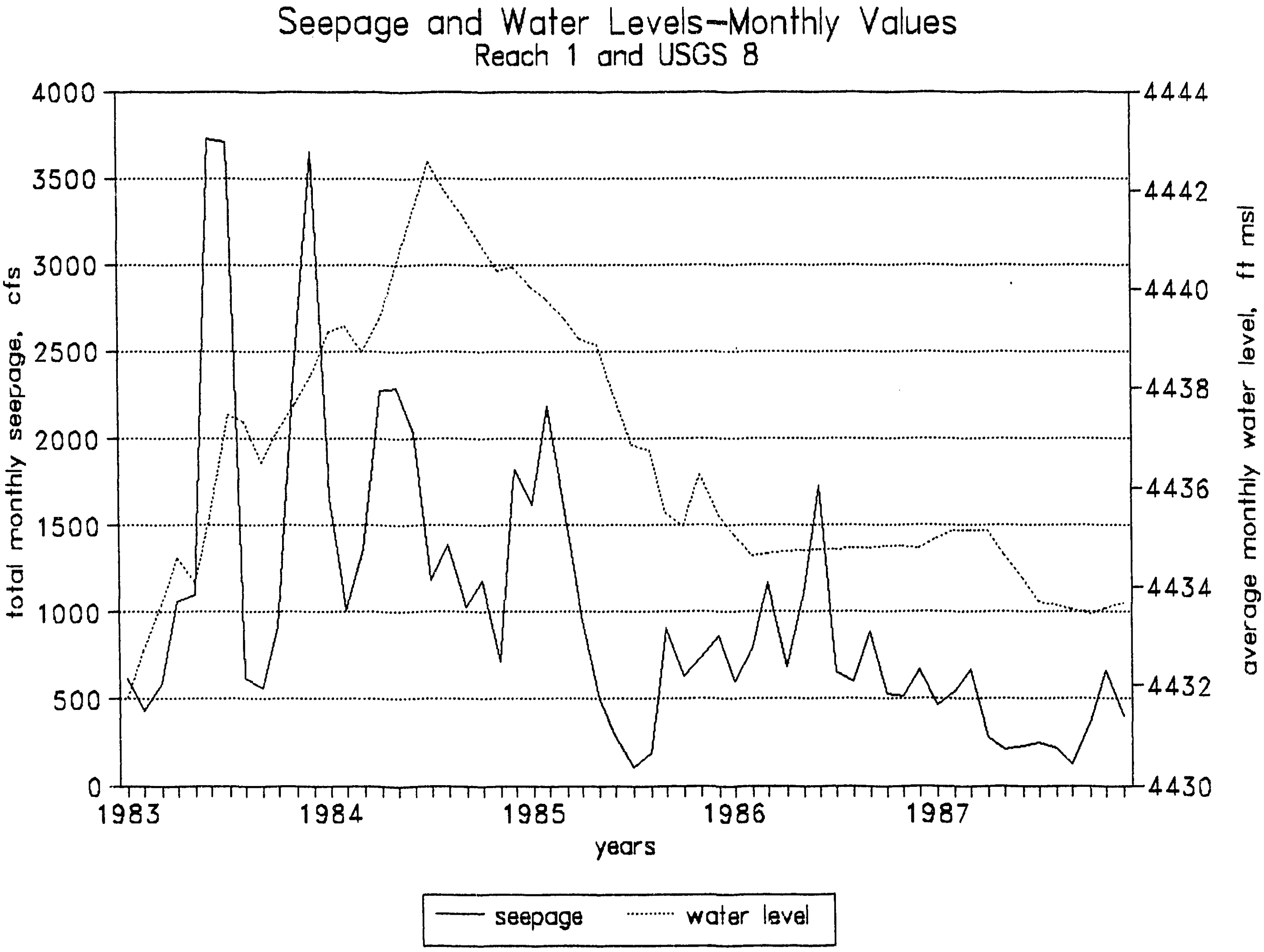

Seepage and Water Levels—Monthly Values
Reach 1 and USGS 8
total monthly seepage, cfs
average monthly water level, ft msl
4000
3500
3000
2500
2000
1500
1000
500
0
4444
4442
4440
4438
4436
4434
4432
4430
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.22

the time series. However, as with the previous analysis, there was some obvious similarity between graphs, with water levels lagging after seepage. A 12-month moving average was then applied to the data, and the resulting graphs are shown in figures 5.23 and 5.24. The time lag is more noticeable in these plots, with the average monthly water levels following consistently in time the total monthly seepage, increasing or decreasing in the same manner, but later in time. Peaks and valleys do not precisely match, but this was not unexpected since there are many other unexplained factors involved in the seepage-groundwater interaction, including time of year, amount of flow in the river, and position of the groundwater table. In the original hypothesis, time lag was assumed independent of these other factors, simply because insufficient data were available to adequately evaluate their effects.

To determine if a significant time-lagged correlation existed between the monthly seepage and average monthly water levels, regression analyses were performed on the data. With groundwater levels as the independent variable, the monthly seepage values were lagged by time periods ranging from two to seven months, and these lagged values used as the independent variable, according to the relationship:

$$G_i = \beta_0 + \beta_1 * S_{i-n}$$

G_i represents the average groundwater level at time i, S_{i-n} is the total monthly seepage n months prior to i, and β_0 and β_1 are regression coefficients.

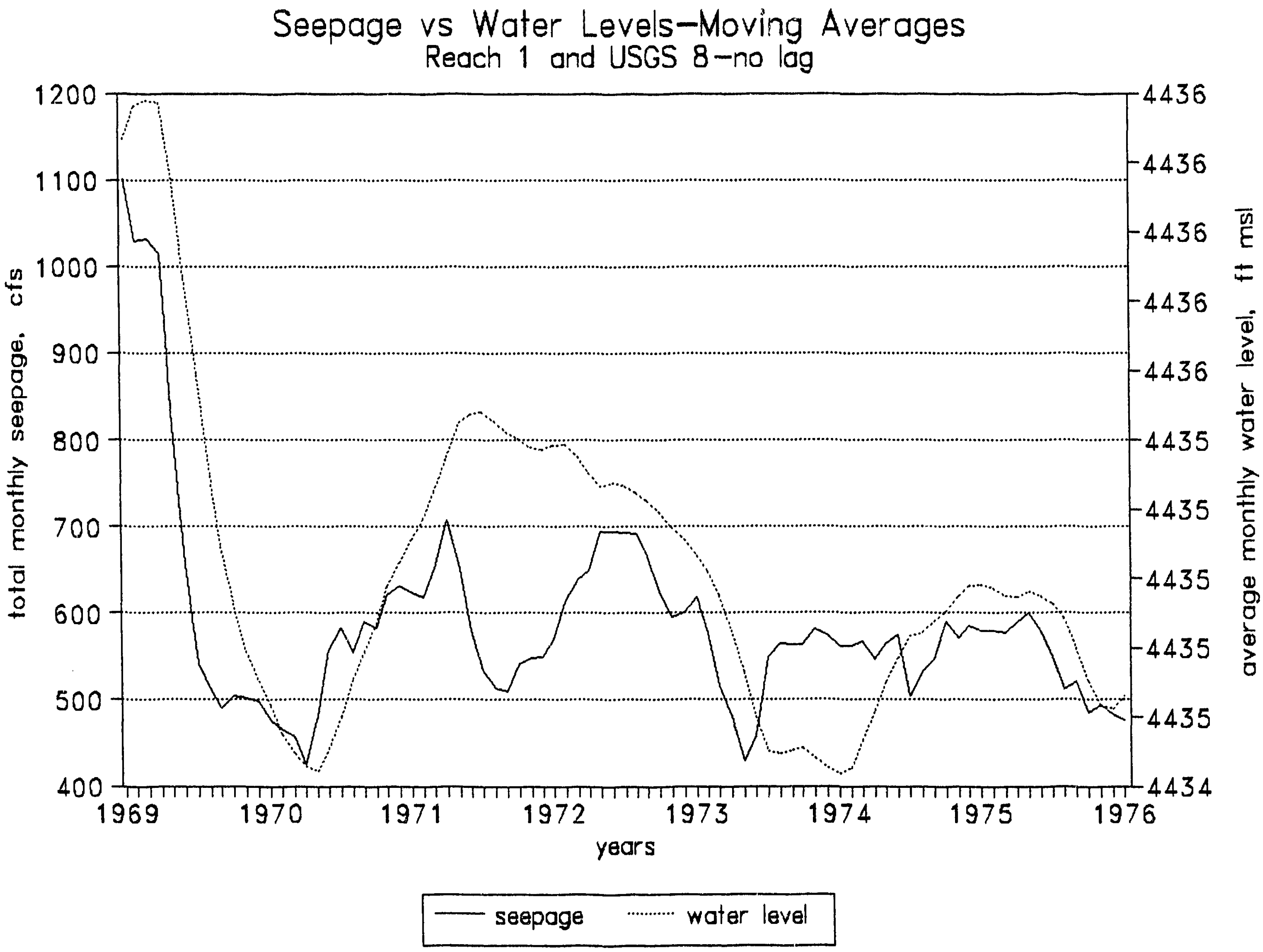

Seepage vs Water Levels—Moving Averages
Reach 1 and USGS 8—no lag
1200
1100
1000
900
800
700
600
500
400
4436
4436
4436
4436
4436
4435
4435
4435
4435
4435
4434
1969
1970
1971
1972
1973
1974
1975
1976
years
total monthly seepage, cfs
average monthly water level, ft msl
seepage
water level

fig 5.23

Seepage vs Water Levels—Moving Averages
Reach 1 and USGS 8—no lag

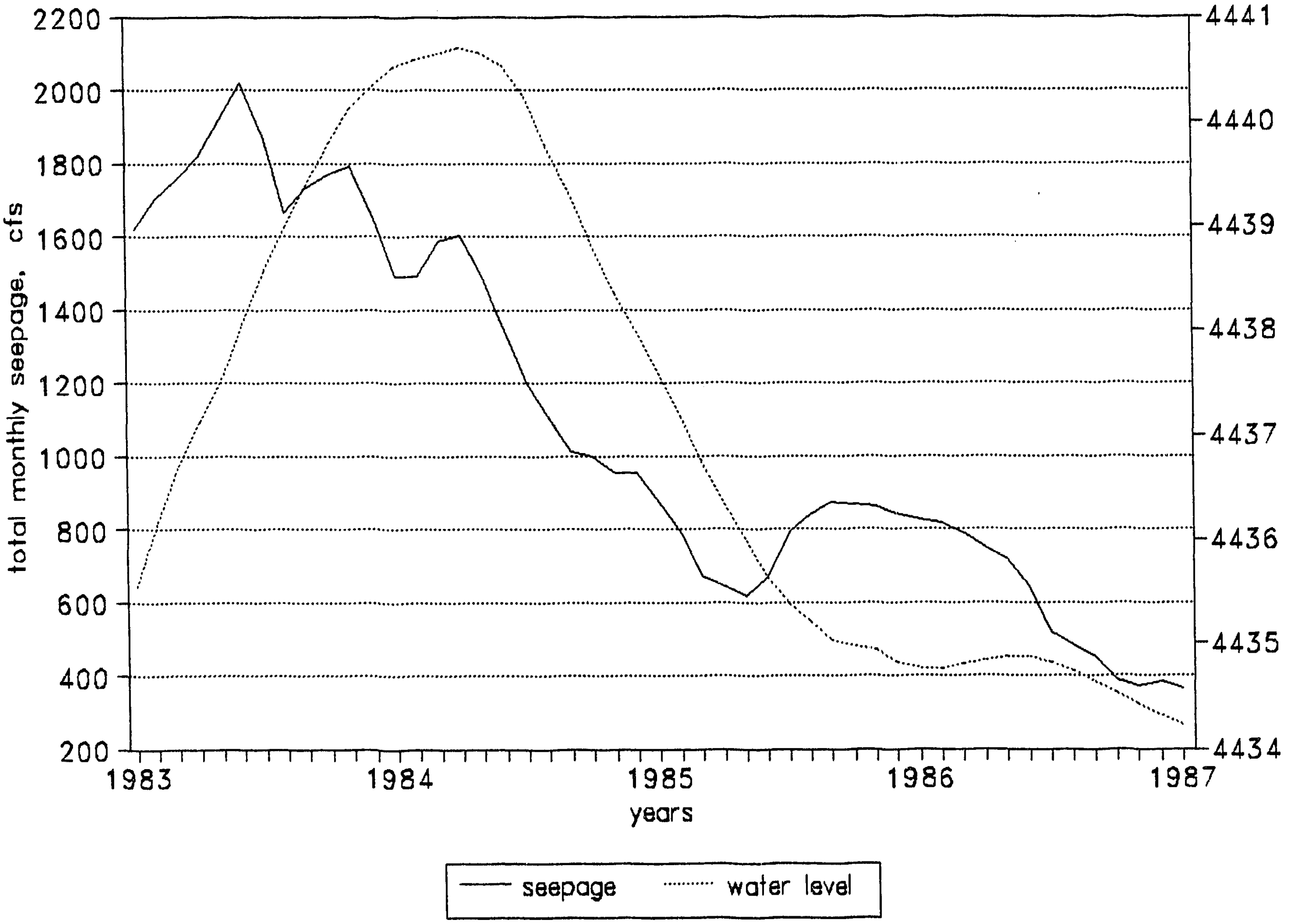


fig 5.24

Initially, these regressions used the 12-month moving averages of the data to obtain a preliminary assessment of the time lag behavior. Since these moving averages have had much of the original data variability removed by the averaging process, it was anticipated that the regressions should display a stronger correlation between the variables than the raw monthly data would yield. It was also anticipated that if a consistent time lag, n, existed, the r^2 value for that value of n would be larger than for any other n. For the values of n tested, the following table presents the r^2 values obtained by the regression analyses:

TABLE I: time lag vs r^2,
Moving Averaged Data

TIME LAG, n, MONTHS	DETERMINATION COEFFICIENT, r^2
2	0.795
3	0.839
4	0.868
5	0.882
6	0.884
7	0.873

The highest resulting determination coefficient, r^2, was 0.884 at an n of six months, demonstrating very strong correlation between the two time series. However, the r^2 at five months was 0.882. There is negligible difference between the two, but it shows that the lag peaks near six months. A regression using more frequent measurements (weekly, daily) would better identify the lag. Figure 5.25 shows a scatter plot of the moving averages of total monthly seepage against average monthly

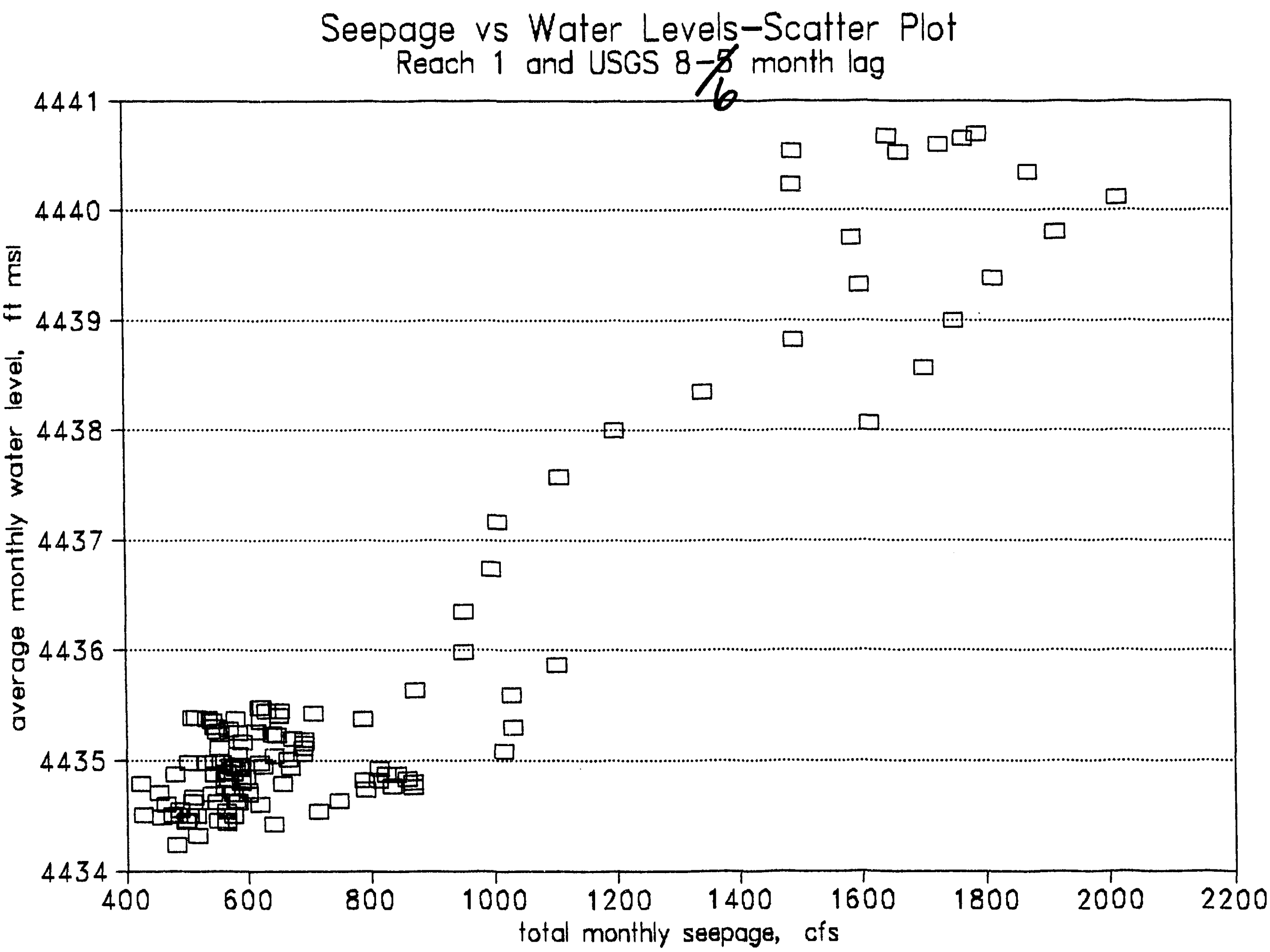

Seepage vs Water Levels-Scatter Plot
Reach 1 and USGS 8-5/6 month lag
average monthly water level, ft msl
total monthly seepage, cfs
4434
4435
4436
4437
4438
4439
4440
4441
400
600
800
1000
1200
1400
1600
1800
2000
2200

fig 5.25

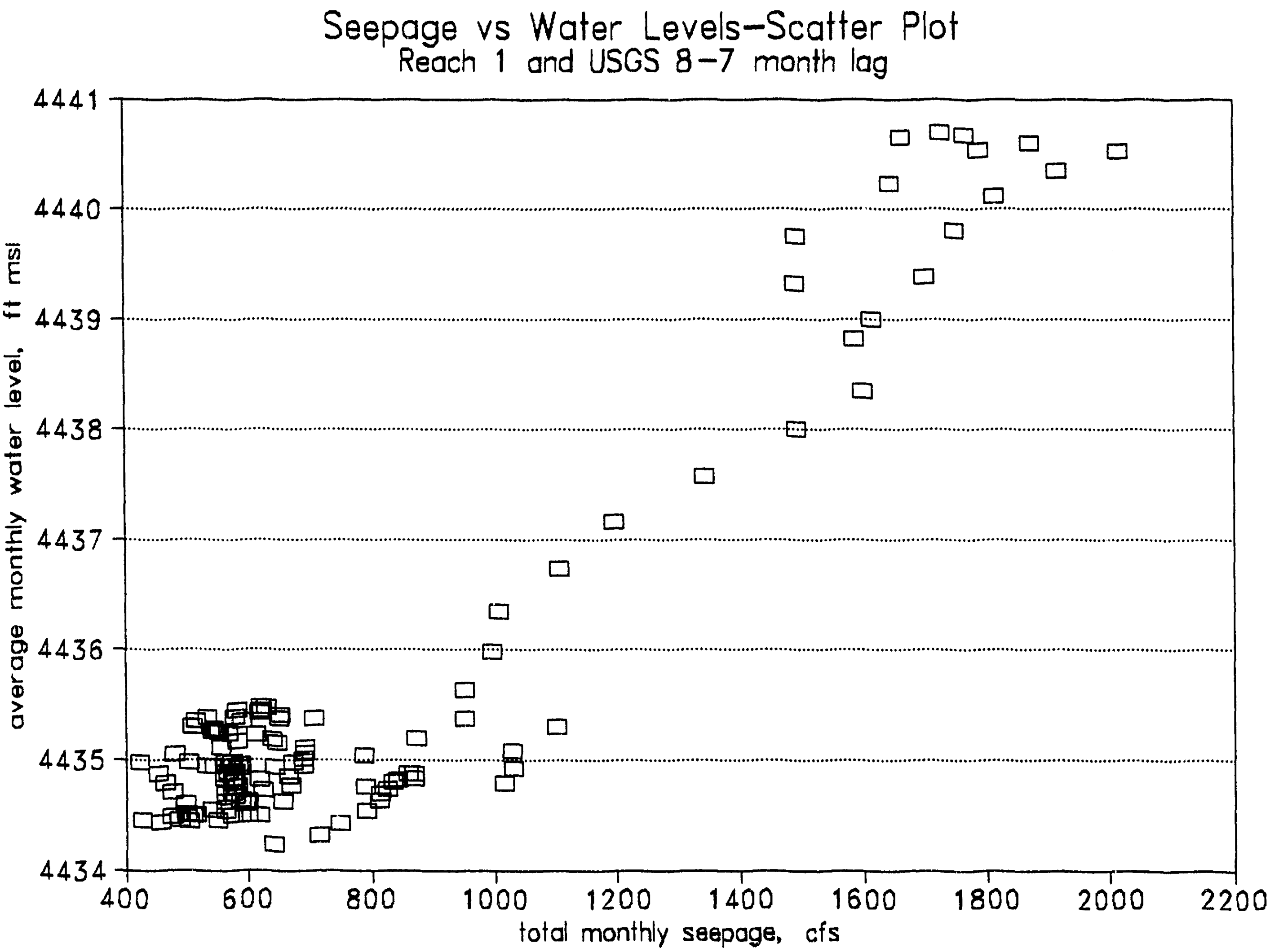
water level for the six month time lag. It illustrates the linearity and correlation between the two variables that the regression analyses suggested.

Following these preliminary assessments, regression analyses were then applied to the raw monthly data, using the same time lag sequence, beginning at n equal to two months. Table II presents the values of r^2 for these regressions.

This approach yielded a seven month time lag as the best correlation, with an r^2 of 0.359. For the same analysis at six months the r^2 was 0.327. Although it was known that the r^2 values for the raw data would be lower, since the data had not been averaged statistically, a different time lag had not been expected. However, a review of Table II indicates that there originally had been very little difference between the r^2 values for n=6 (r^2=0.884) and n=7 (r^2=0.873). Figure 5.26 presents a scatter plot of the moving averaged data with n=7, for comparison with figure 5.25.

TABLE II: time lag vs r^2, Raw Monthly Data

TIME LAG, n, MONTHS	DETERMINATION COEFFICIENT, r^2
2	0.344
3	0.312
4	0.294
5	0.294
6	0.327
7	0.359



Seepage vs Water Levels-Scatter Plot
Reach 1 and USGS 8-7 month lag
average monthly water level, ft msl
4441
4440
4439
4438
4437
4436
4435
4434
400
600
800
1000
1200
1400
1600
1800
2000
2200
total monthly seepage, cfs

fig 5.26

The results from these analyses indicate that although the use of moving averaged data makes the graphical presentation of the time series easier to read and compare, there is time lag sensitivity lost in the process. However, the regression on both the moving averaged and raw data showed good correlation at both a six-month and seven-month time lag with reasonably consistent results. From this it was assumed that during some intervals of the study period six months was a dominant lag time, and at others a seven month lag dominated.

SPREADING AREAS AND USGS 9

The seepage process in the spreading areas is more direct than in the river reaches, since almost all of the water entering the basins is lost through infiltration and percolation. In addition, the seepage is confined to a relatively small area, with the selected well located in very close proximity. Therefore, the correlation between the two was anticipated to be high.

The plots of monthly values of seepage and water level against time can be seen in figures 5.27 and 5.28. Again, the time lag and similarity between graphs is quite noticeable. Figures 5.29 and 5.30 show the 12-month moving averages of the data. Regressions on the moving averaged data yielded an r^2 of 0.937 at five months as the best correlation. A regression on the monthly data gave an r^2 of 0.683 at five months. For both analyses, the five month correlation was the highest. Again, for the moving averaged data, the loss in sensitivity is demonstrated

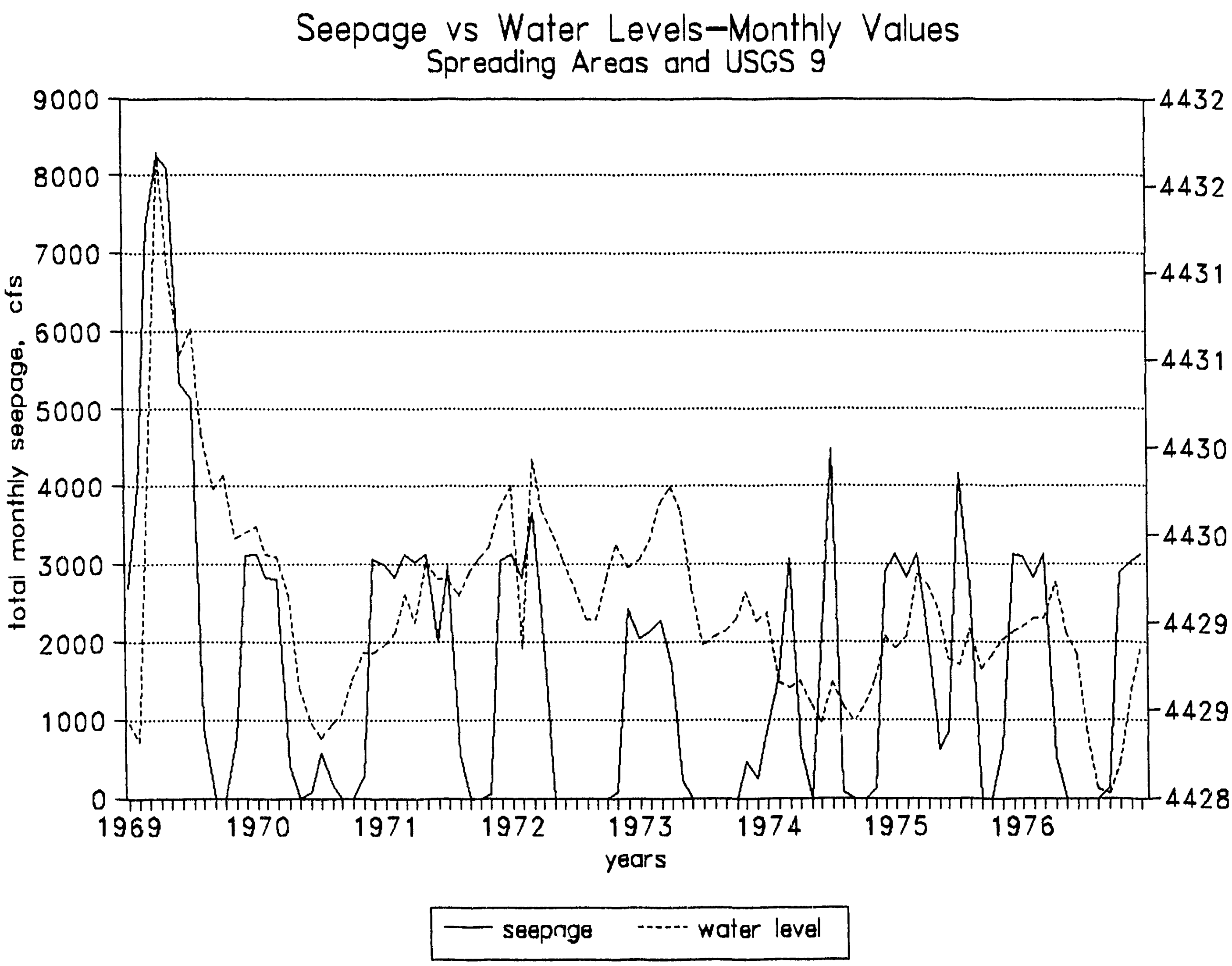

Seepage vs Water Levels—Monthly Values
Spreading Areas and USGS 9
total monthly seepage, cfs
average monthly water level, ft msl
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
4432
4432
4431
4431
4430
4430
4429
4429
4428
1969
1970
1971
1972
1973
1974
1975
1976
years
seepnge
water level

fig 5.27

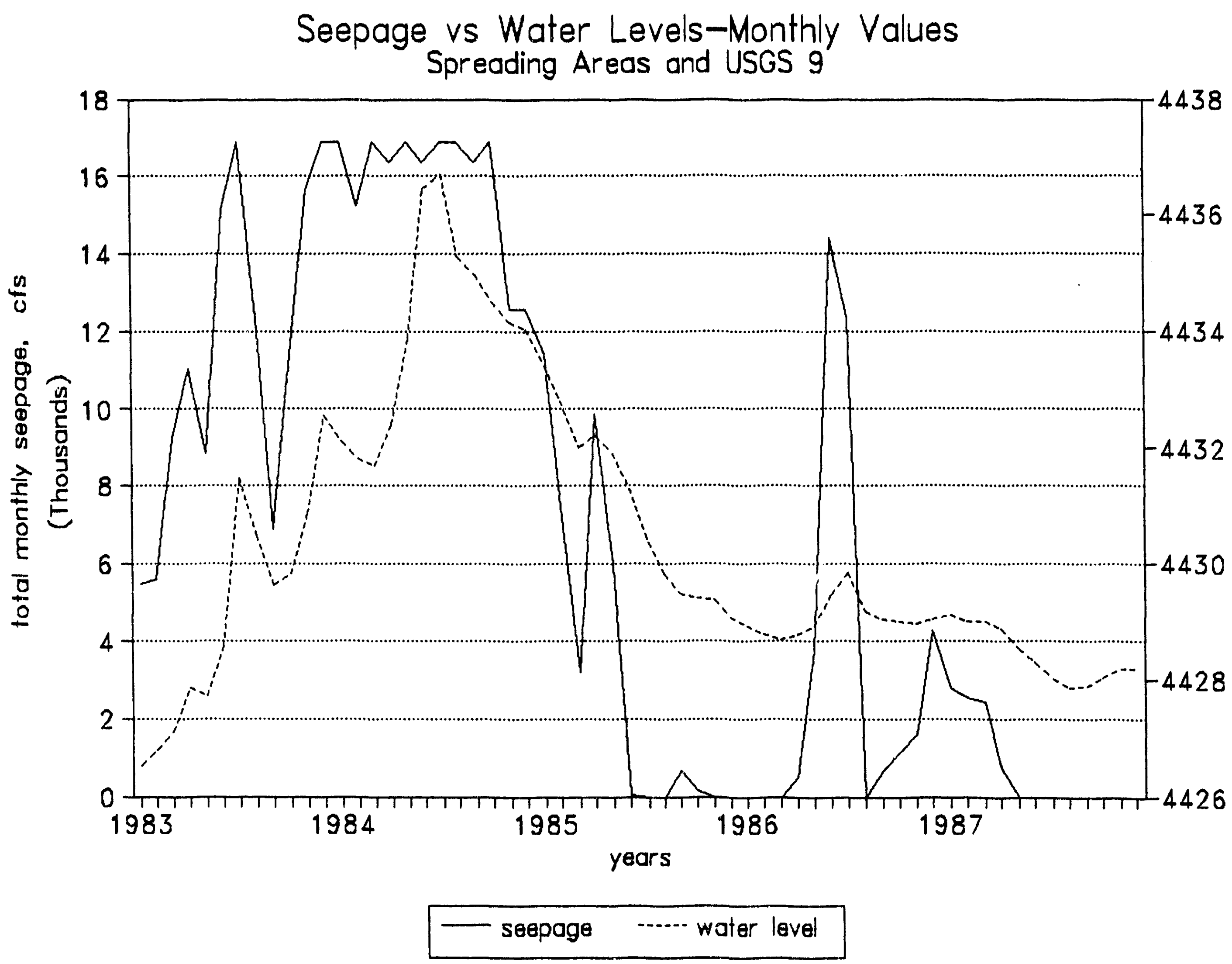

Seepage vs Water Levels—Monthly Values
Spreading Areas and USGS 9
total monthly seepage, cfs
(Thousands)
0
2
4
6
8
10
12
14
16
18
average monthly water level, ft msl
4426
4428
4430
4432
4434
4436
4438
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.28

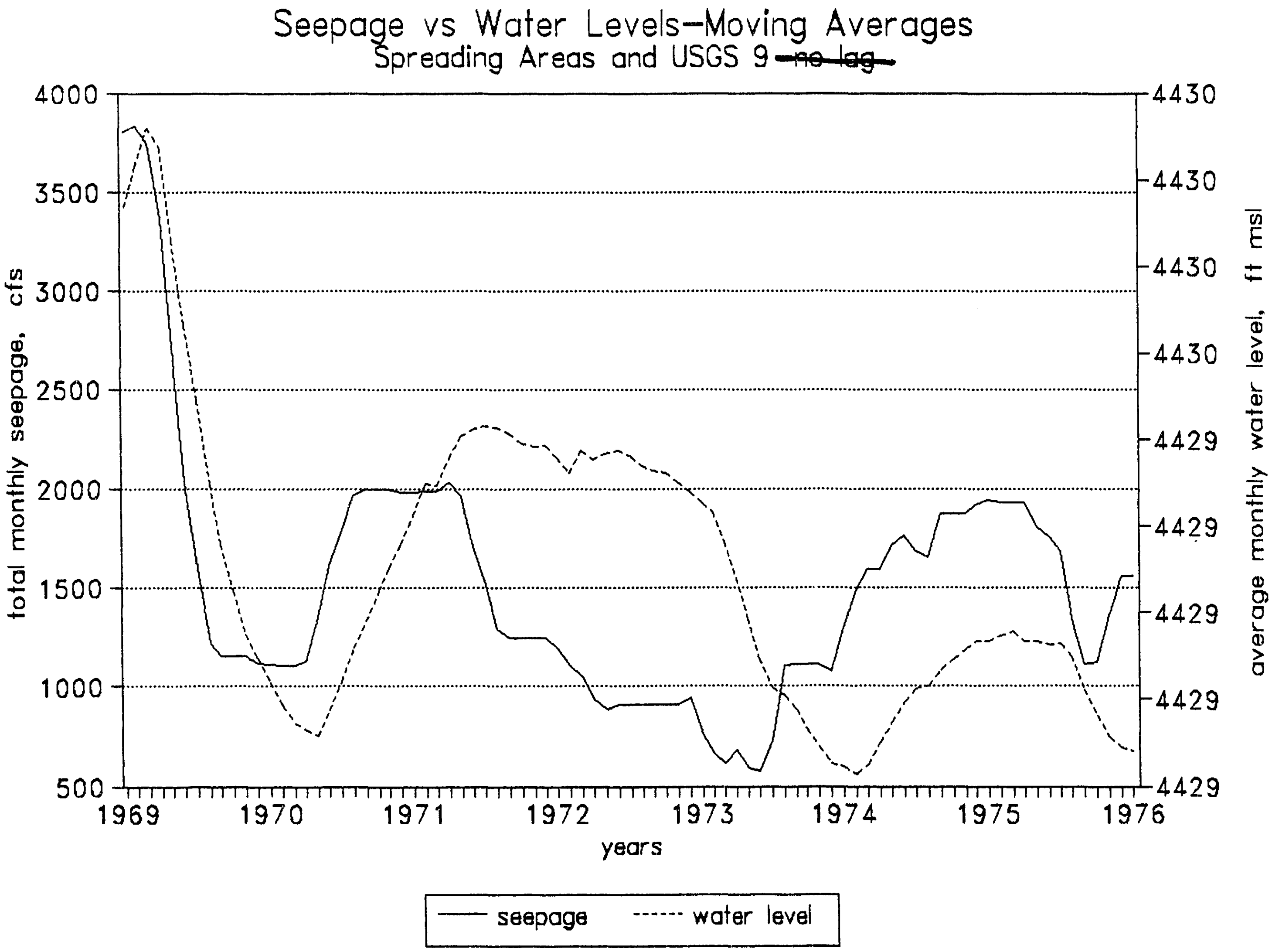
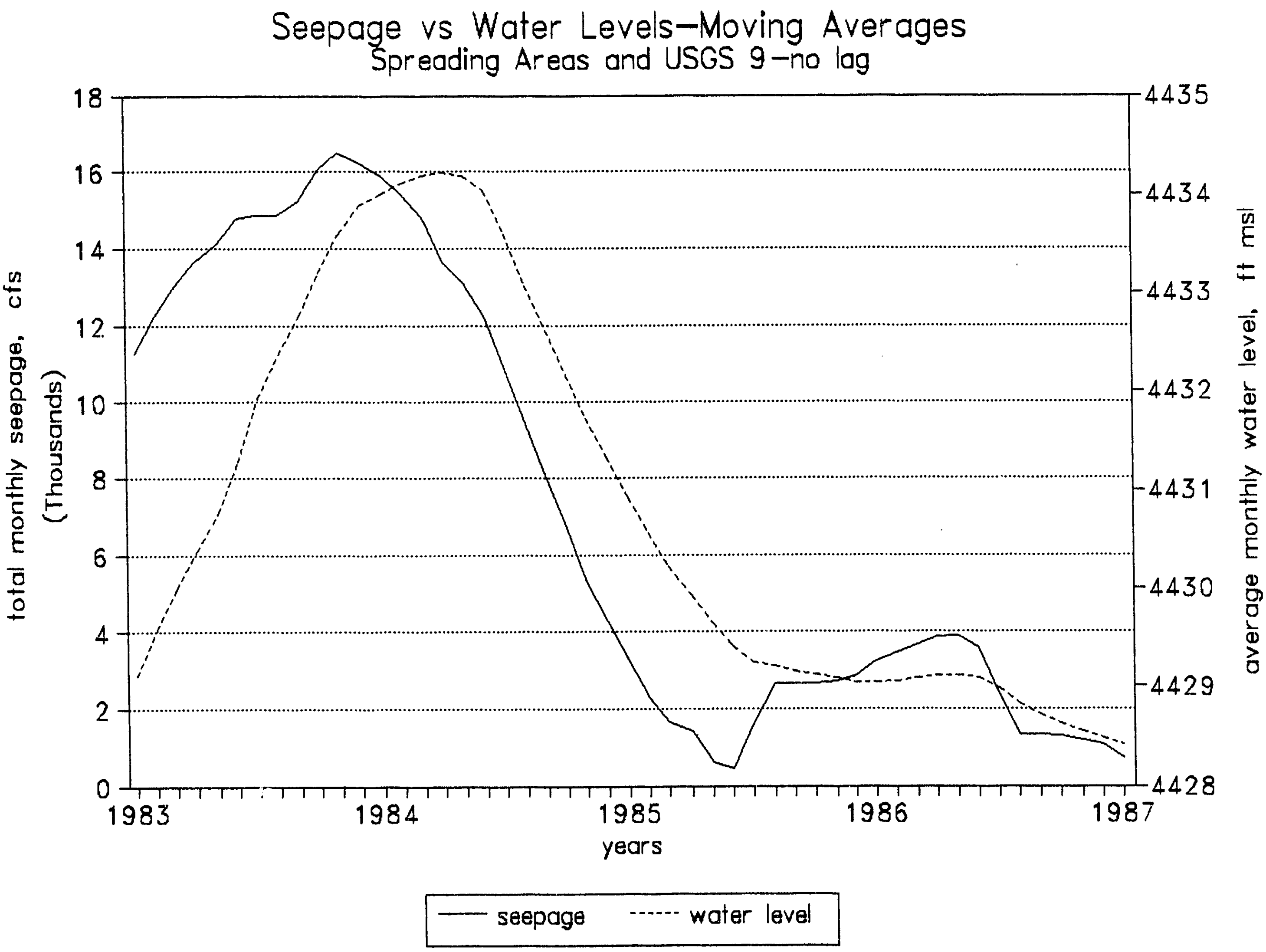

Seepage vs Water Levels—Moving Averages
Spreading Areas and USGS 9 ~~no lag~~
4000
3500
3000
2500
2000
1500
1000
500
total monthly seepage, cfs
4430
4430
4430
4430
4429
4429
4429
4429
4429
average monthly water level, ft msl
1969
1970
1971
1972
1973
1974
1975
1976
years
seepage
water level

fig 5.~~30~~ 29

2A



Seepage vs Water Levels—Moving Averages
Spreading Areas and USGS 9—no lag
total monthly seepage, cfs (Thousands)
average monthly water level, ft msl
18
16
14
12
10
8
6
4
2
0
4435
4434
4433
4432
4431
4430
4429
4428
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.30

with the small difference between time lags of four and five months. Table III presents the r^2 values versus n for the moving averaged and the raw data.

Scatter plots of the two regressions with n=5 months can be seen in figures 5.31 and 5.32. The relationship in figure 5-31 is very nearly linear and visually demonstrates why the r^2 for the moving averaged data was so high. Since the raw data has

TABLE III: Time Lags vs r^2, Moving Average and Raw Data

TIME LAG, n, MONTHS	MOVING AVERAGE r^2	RAW DATA r^2
2	0.873	0.611
3	0.915	0.635
4	0.936	0.666
5	0.937	0.683
6	0.917	0.679
7	0.883	0.644

considerably greater variability, its scatter plot, figure 5-12, does not demonstrate this degree of linearity. Compared to the previous reach 1 analysis, the correlation coefficients for the spreading areas were considerably higher, especially for the raw data. It was concluded that the results were better than those for reach 1, for the reason previously stated.

REACH 1, SPREADING AREAS, AND USGS 9

Plots for this comparison can be seen in figures 5.33 through 5.38. Seepage here was defined as the sum of the seepage from reach 1 and the spreading areas, and was correlated again to the water levels in USGS 9. This analysis was done to determine

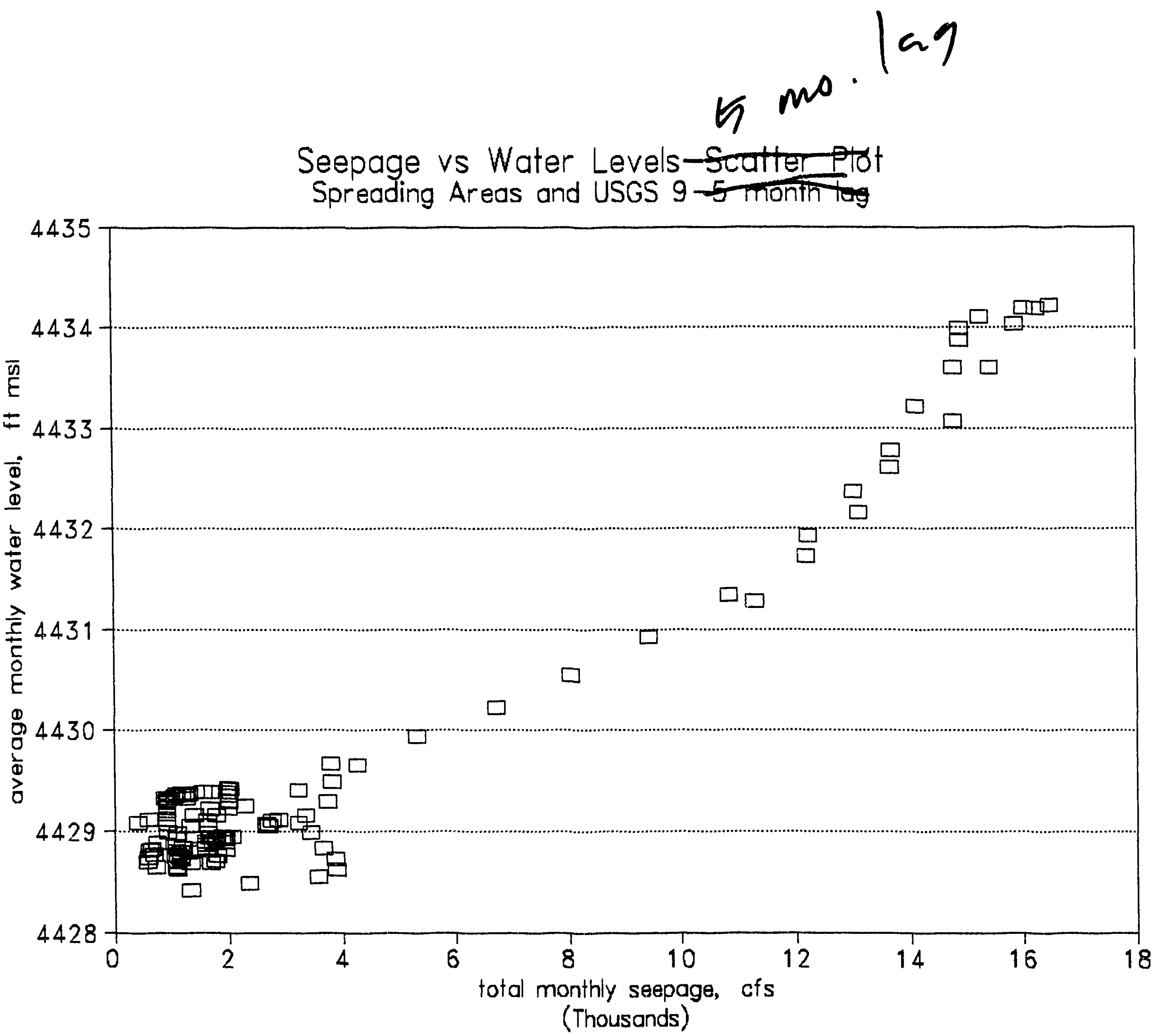
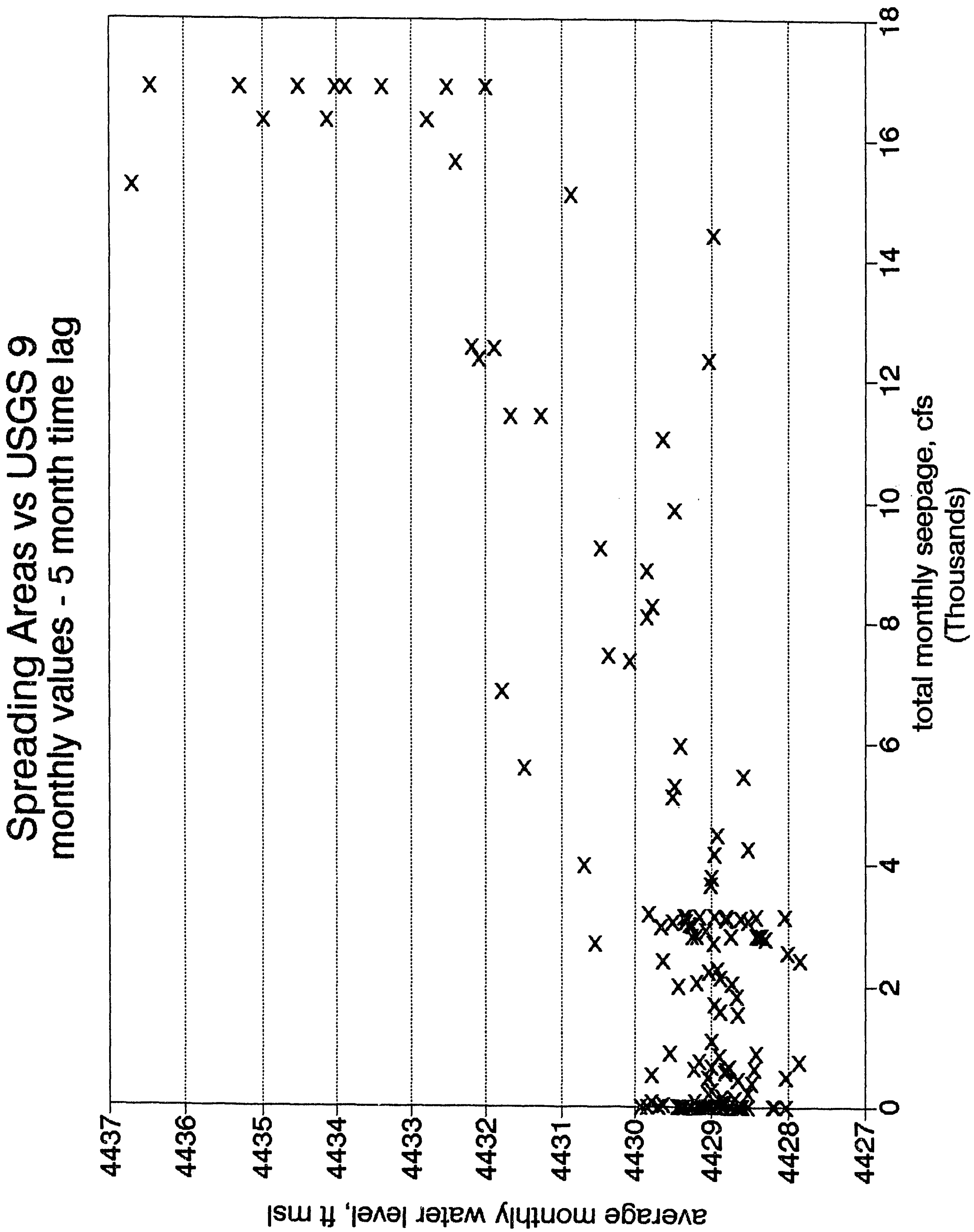

5 mo. lag
Seepage vs Water Levels ~~Scatter Plot~~
Spreading Areas and USGS 9 ~~5 month lag~~
average monthly water level, ft msl
4435
4434
4433
4432
4431
4430
4429
4428
0
2
4
6
8
10
12
14
16
18
total monthly seepage, cfs
(Thousands)

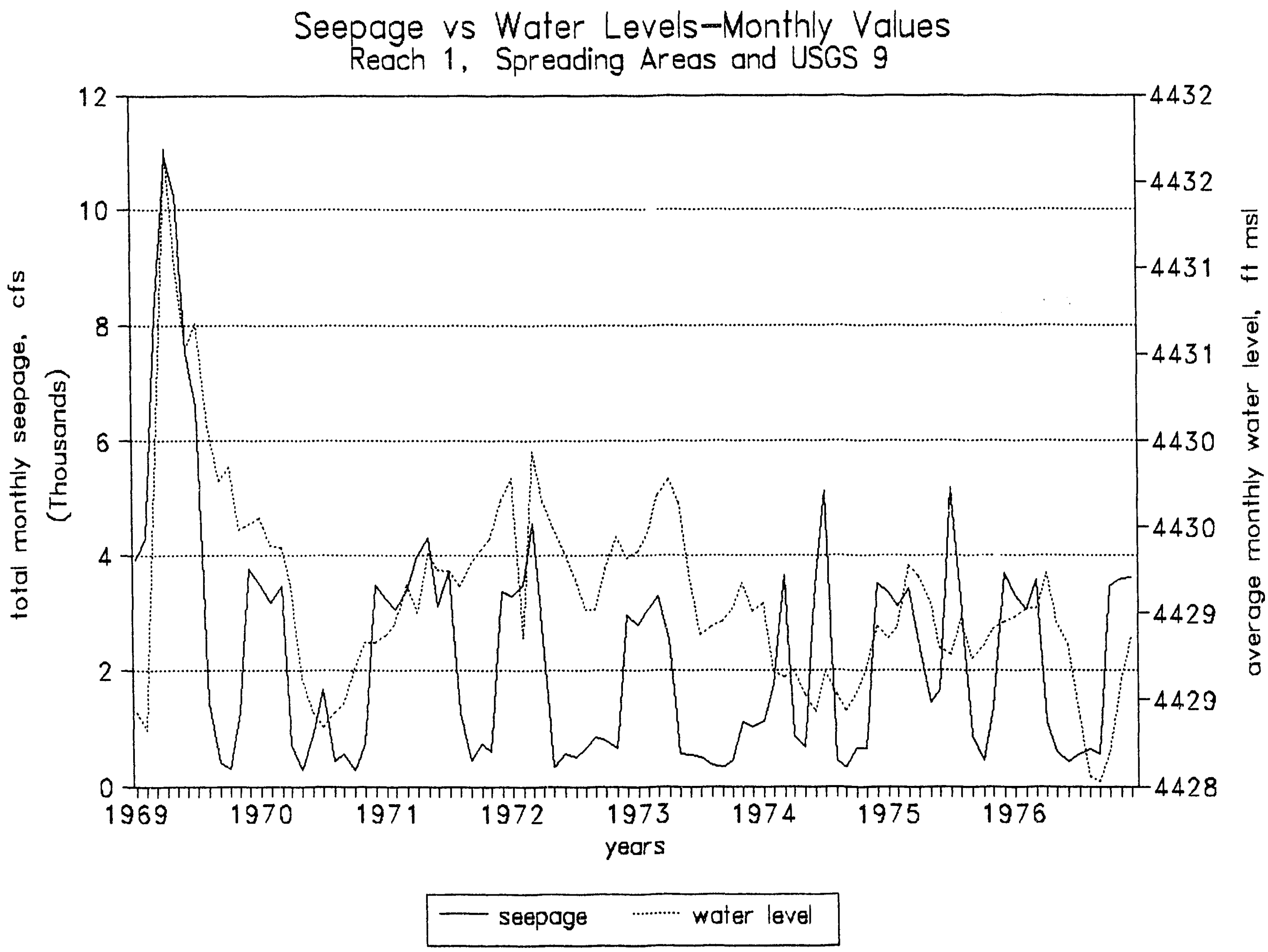
fig 5.31



Spreading Areas vs USGS 9
monthly values - 5 month time lag
average monthly water level, ft msl
4437
4436
4435
4434
4433
4432
4431
4430
4429
4428
4427
0
2
4
6
8
10
12
14
16
18
total monthly seepage, cfs
(Thousands)

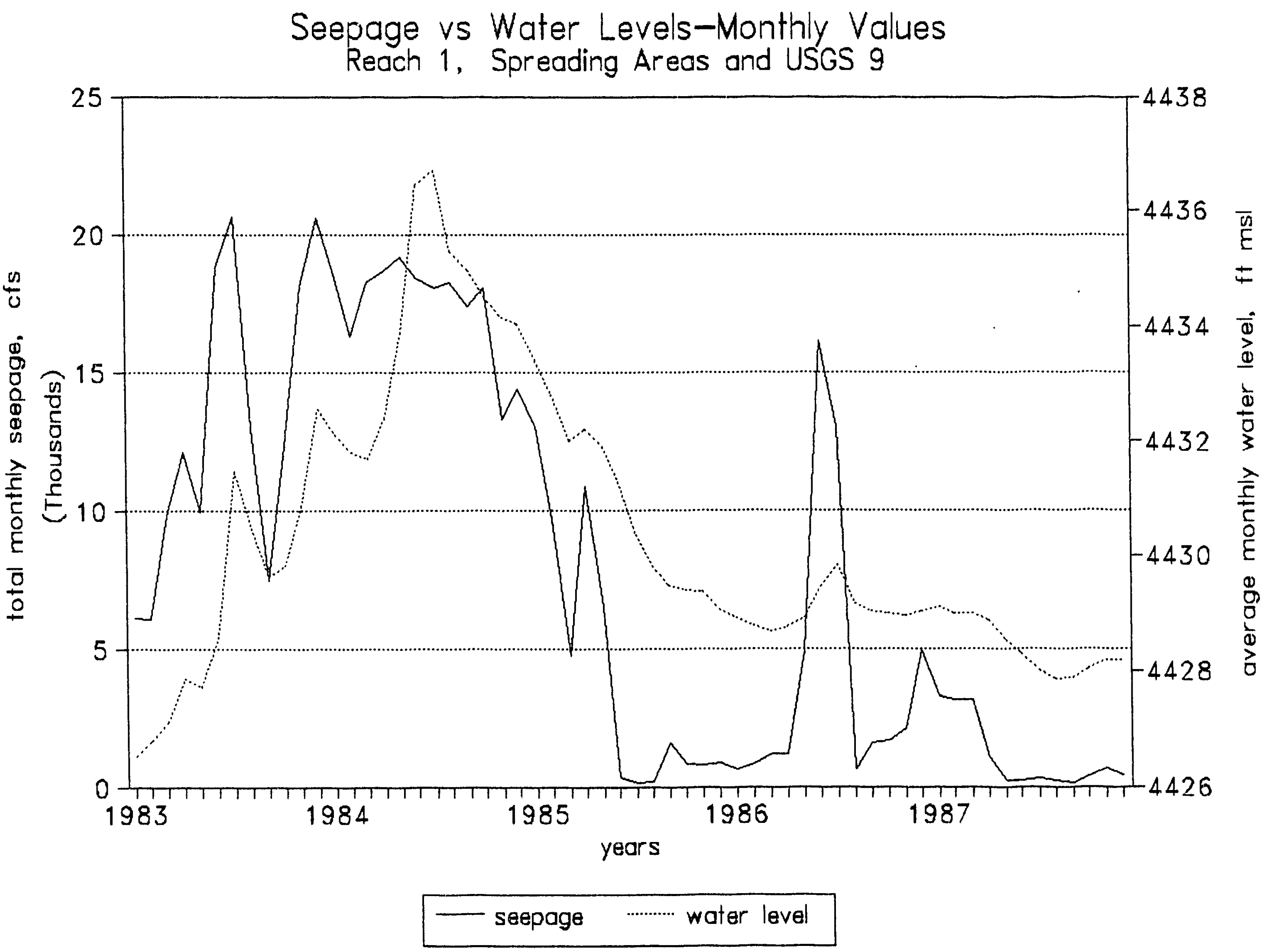
fig 5.32

6 A



Seepage vs Water Levels—Monthly Values
Reach 1, Spreading Areas and USGS 9
total monthly seepage, cfs
(Thousands)
average monthly water level, ft msl
12
10
8
6
4
2
0
4432
4432
4431
4431
4430
4430
4429
4429
4428
1969
1970
1971
1972
1973
1974
1975
1976
years
seepage
water level

fig 5.33



Seepage vs Water Levels—Monthly Values
Reach 1, Spreading Areas and USGS 9
total monthly seepage, cfs
(Thousands)
average monthly water level, ft msl
0
5
10
15
20
25
4426
4428
4430
4432
4434
4436
4438
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.34

6A

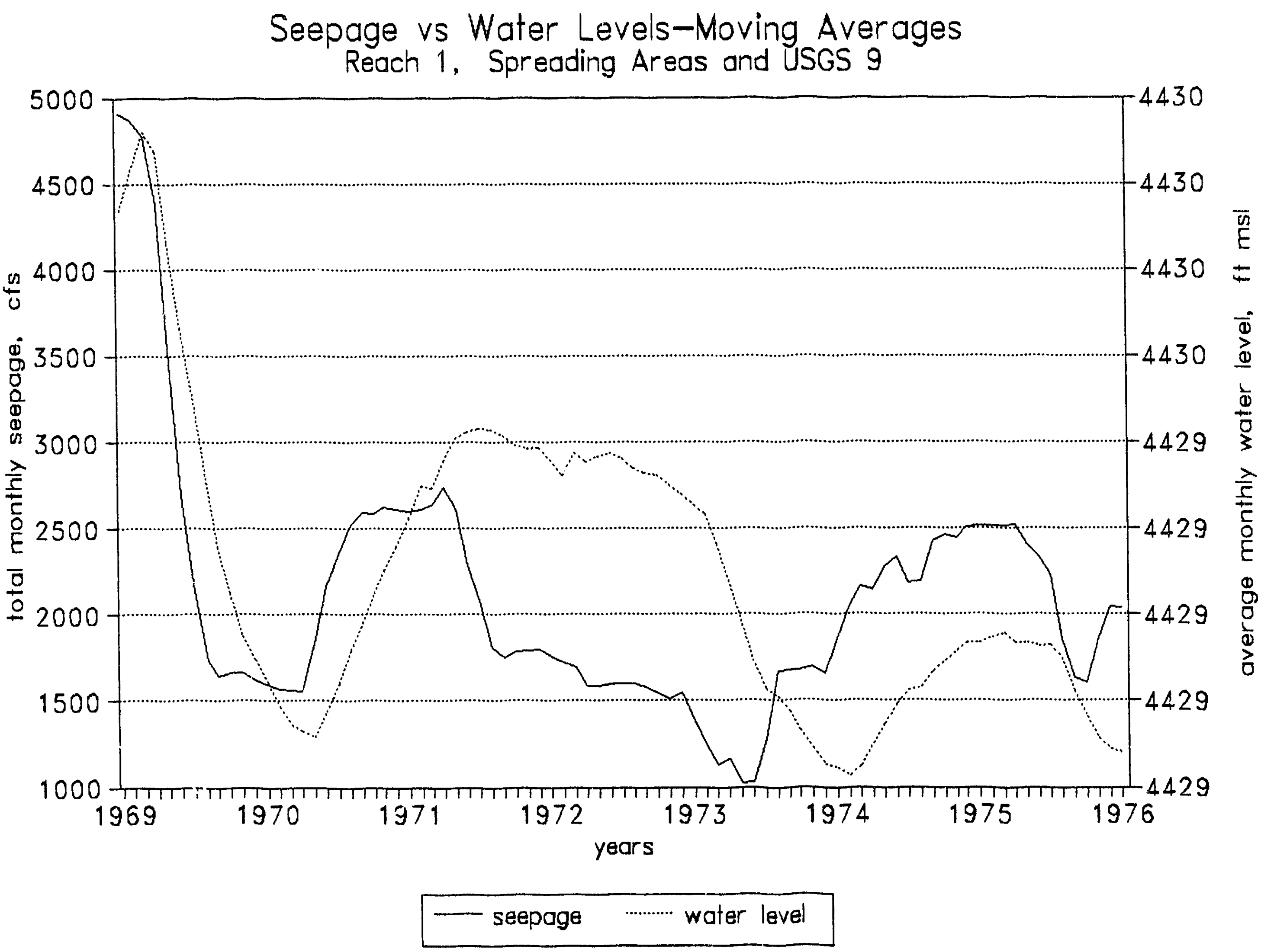
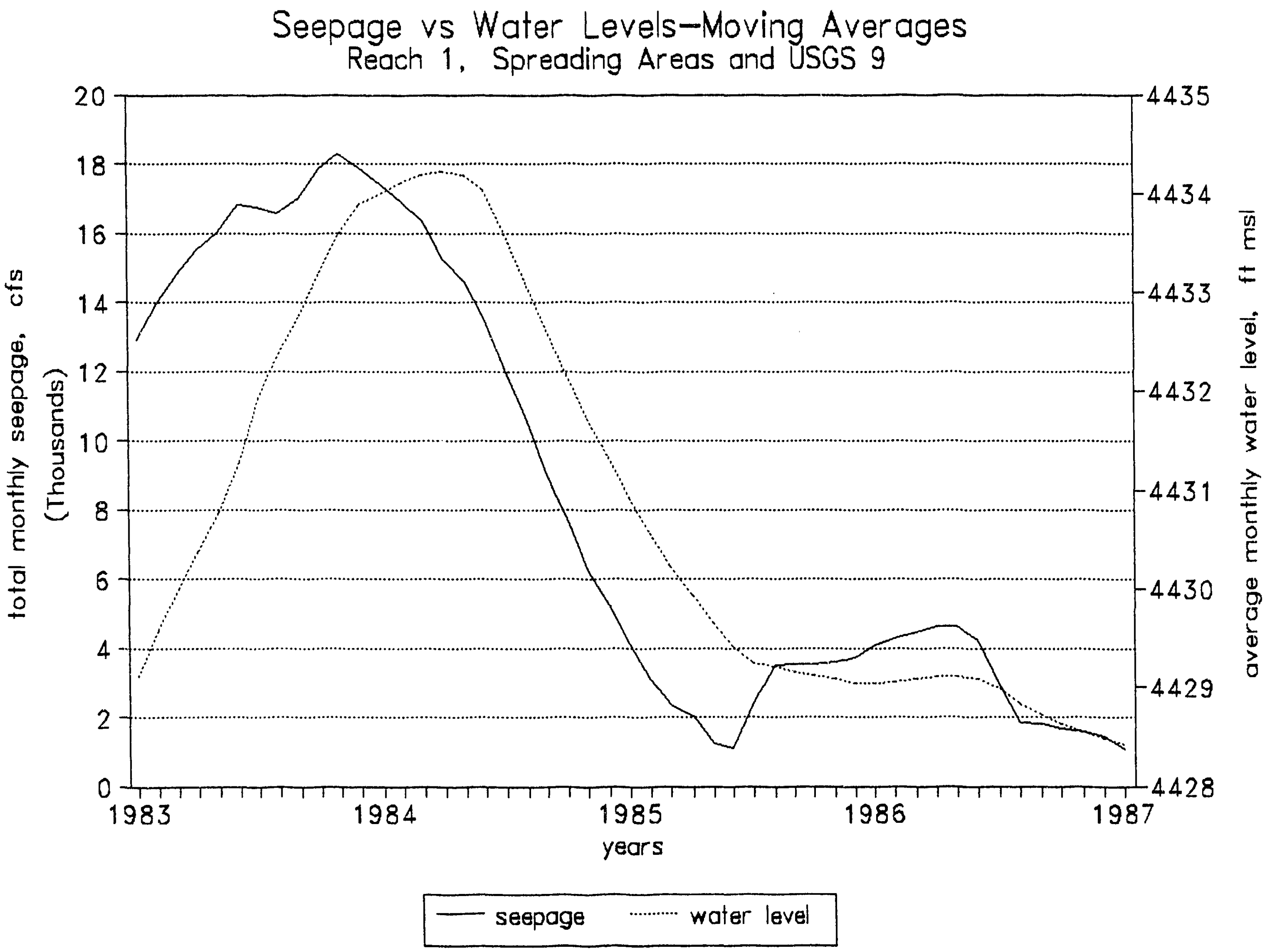

Seepage vs Water Levels—Moving Averages
Reach 1, Spreading Areas and USGS 9
total monthly seepage, cfs
average monthly water level, ft msl
5000
4500
4000
3500
3000
2500
2000
1500
1000
4430
4430
4430
4430
4429
4429
4429
4429
4429
1969
1970
1971
1972
1973
1974
1975
1976
years
seepage
water level

fig 5.35

7A



Seepage vs Water Levels—Moving Averages
Reach 1, Spreading Areas and USGS 9
total monthly seepage, cfs
(Thousands)
average monthly water level, ft msl
0
2
4
6
8
10
12
14
16
18
20
4428
4429
4430
4431
4432
4433
4434
4435
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.36

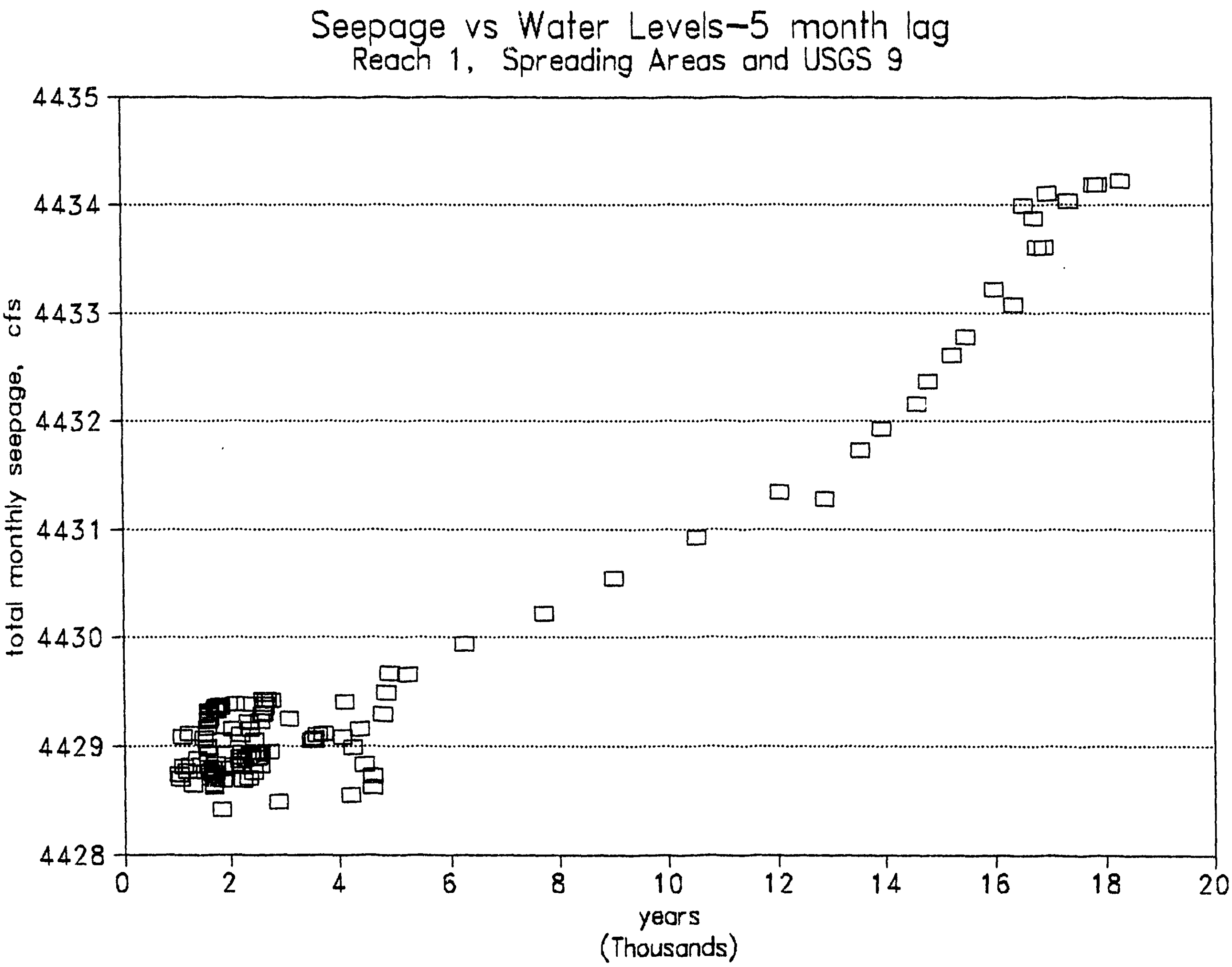

Seepage vs Water Levels—5 month lag
Reach 1, Spreading Areas and USGS 9
total monthly seepage, cfs
4435
4434
4433
4432
4431
4430
4429
4428
0
2
4
6
8
10
12
14
16
18
20
years
(Thousands)

fig 5.37

Fig 5-18

Reach 1, Spreading Areas vs USGS 9
monthly values - 5 month time lag

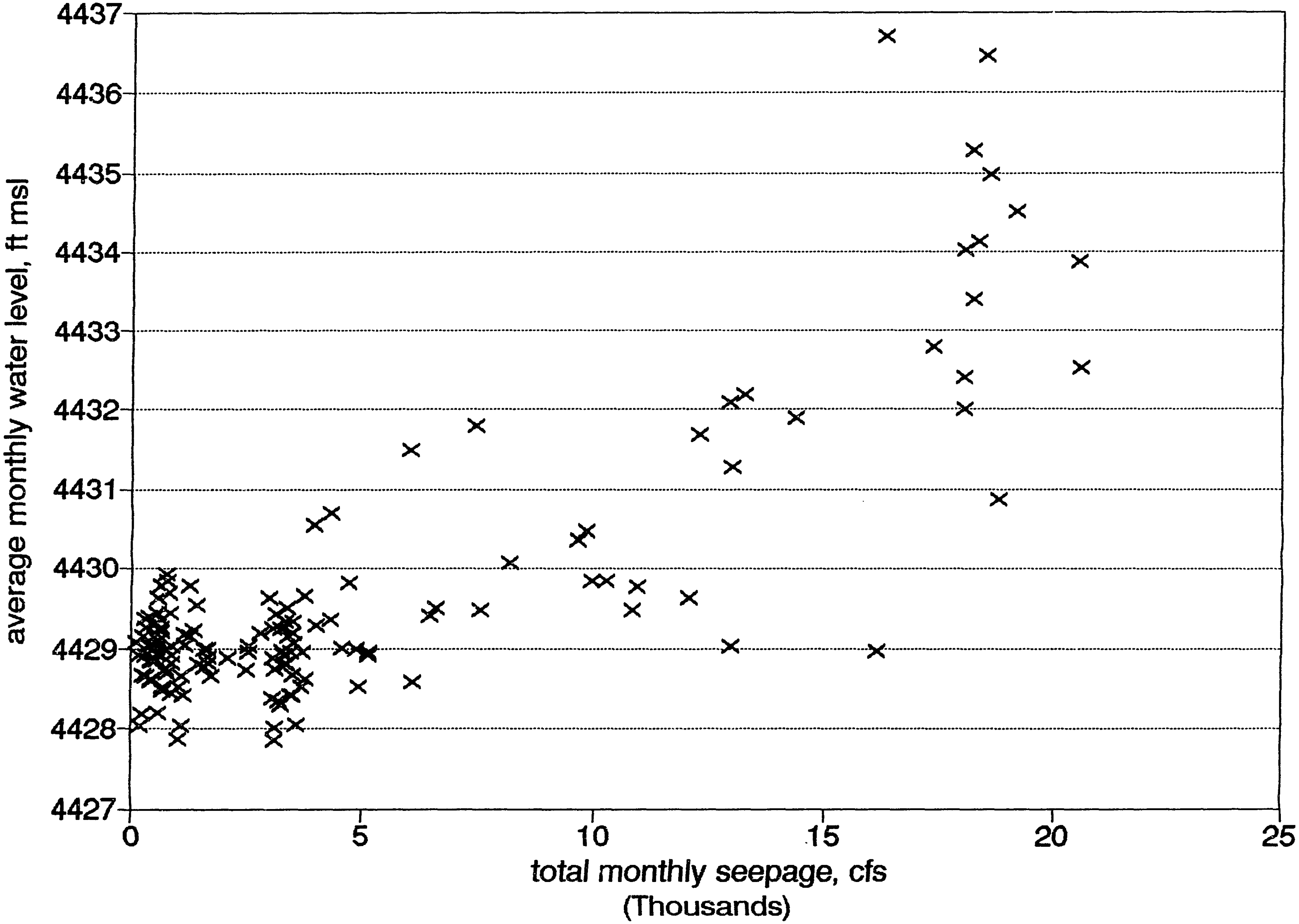


Fig 5.38

if seepage from reach 1 would have any additional impact on the time lag calculated between seepage from the spreading areas and USGS 9. Regression analyses using the combined data sets yielded an r^2 of 0.94 at a five-month time lag for moving averages, and an r^2 of 0.58 at five months for the raw monthly data. These numbers did not differ from the comparison of the spreading areas alone and USGS 9, primarily because the volume of seepage from the spreading areas far outweighed that from reach one. (For the periods of time in the study, the average seepage rate from the ponds was 3699.5 cfs, and 782.3 cfs from reach 1.)

REACH 2 AND USGS 9

Reach 2 is located north and east of USGS 9, and it was believed that a good correlation would exist between seepage from reach 2 and water levels in the well since regional groundwater flow is to the southwest. Again, the same correlation procedures used previously were applied, and the 12-month moving averages were plotted (see figures 5.39 and 5.40). As is demonstrated in the plots, there was little correlation, especially in the period from 1983-1987. There appeared to be some correlation during the first period, but a regression on the data yielded a maximum r^2 of 0.017 at n=2 months. For the second period of study, the strongest correlation was $r^2=0.05$ at n=6 months. Both of these determination coefficients are meaningless since they are nearly zero.

Only one theory was speculated as to why no correlation existed between seepage from reach 2 and water levels in USGS 9.

Seepage vs Water Levels—Moving Averages
Reach 2 and USGS 9—no time lag

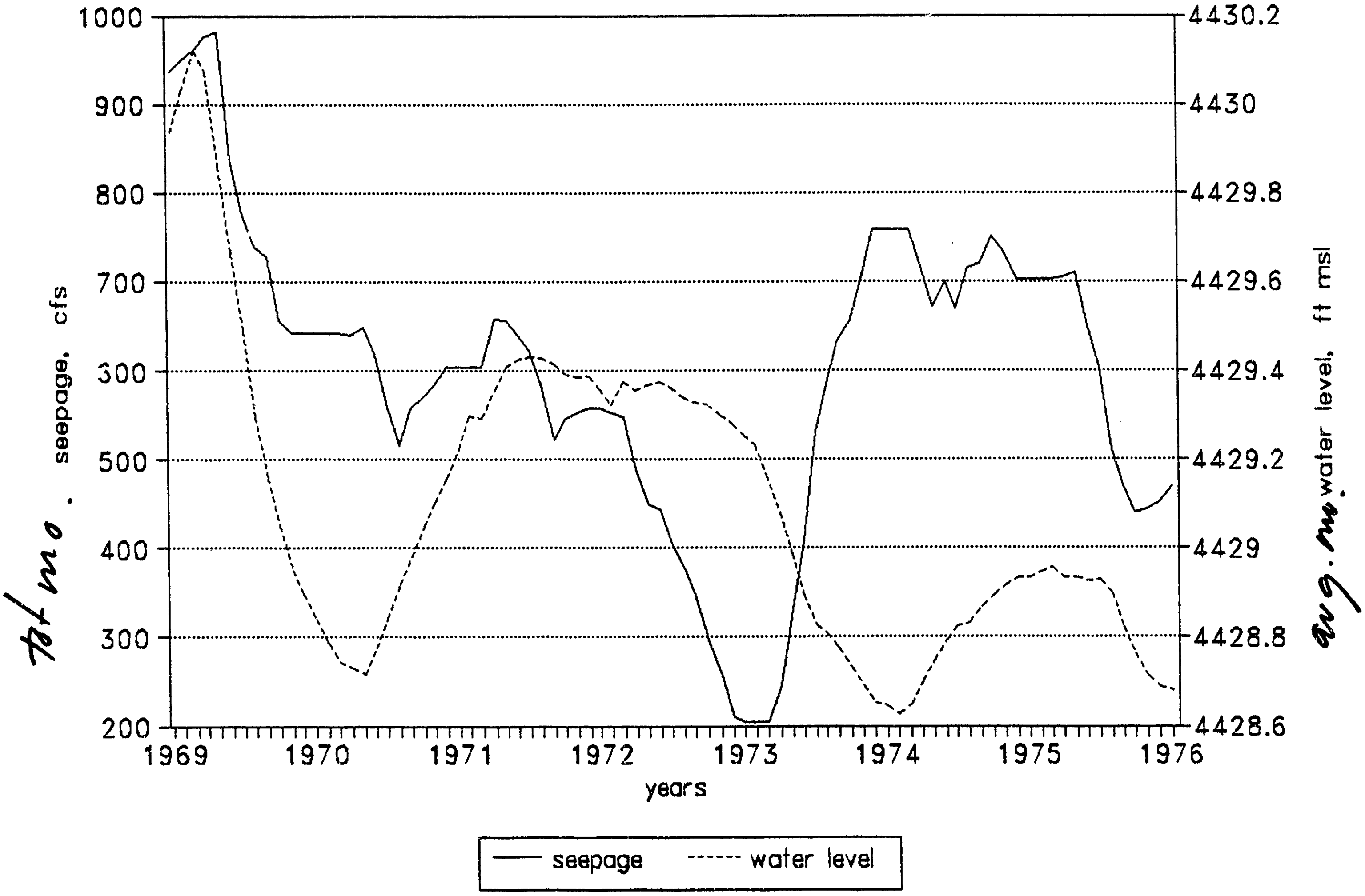


fig 5.39

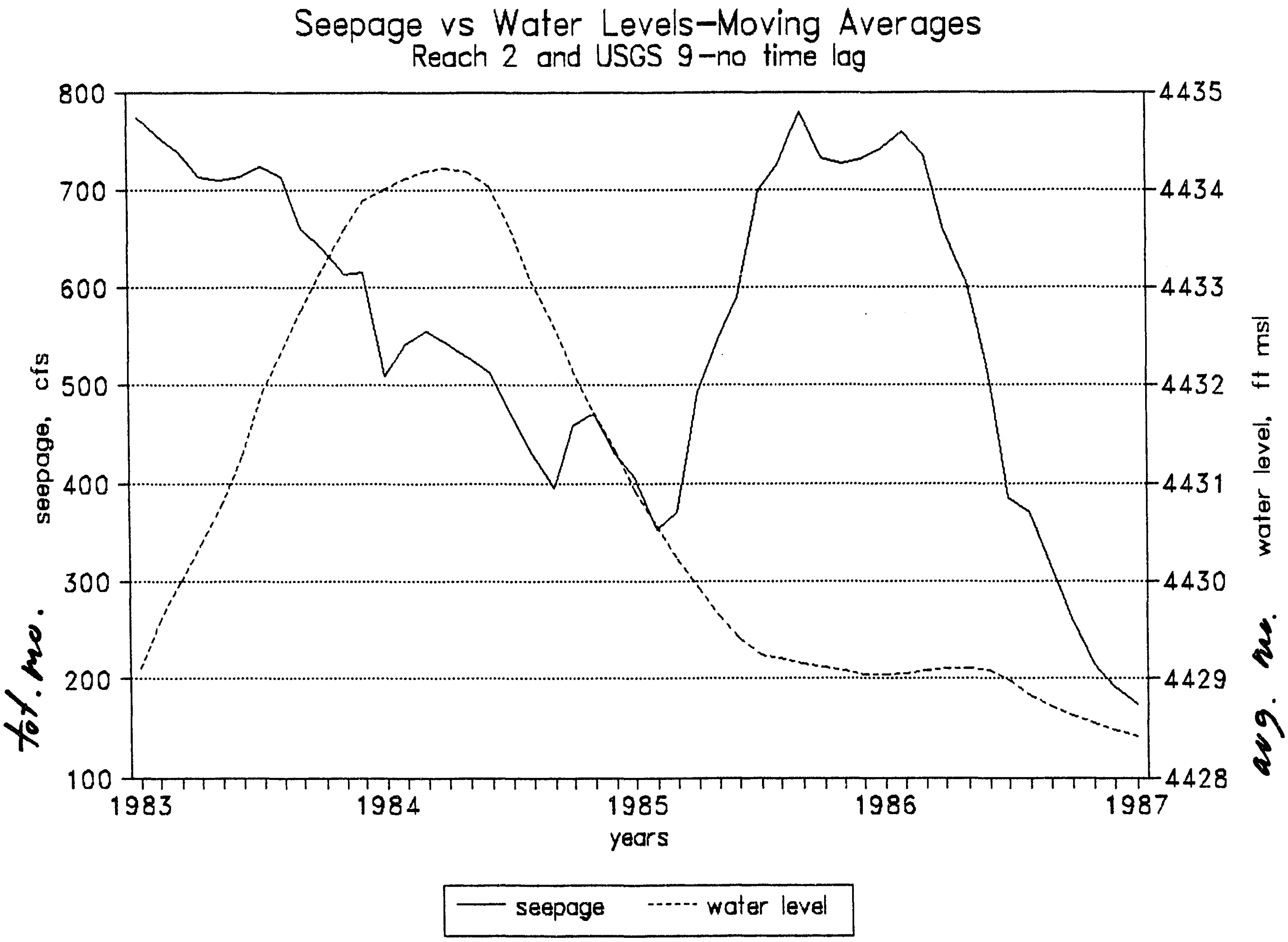

Seepage vs Water Levels—Moving Averages
Reach 2 and USGS 9—no time lag
seepage, cfs
tot. mo.
water level, ft msl
avg. mo.
800
700
600
500
400
300
200
100
4435
4434
4433
4432
4431
4430
4429
4428
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.40

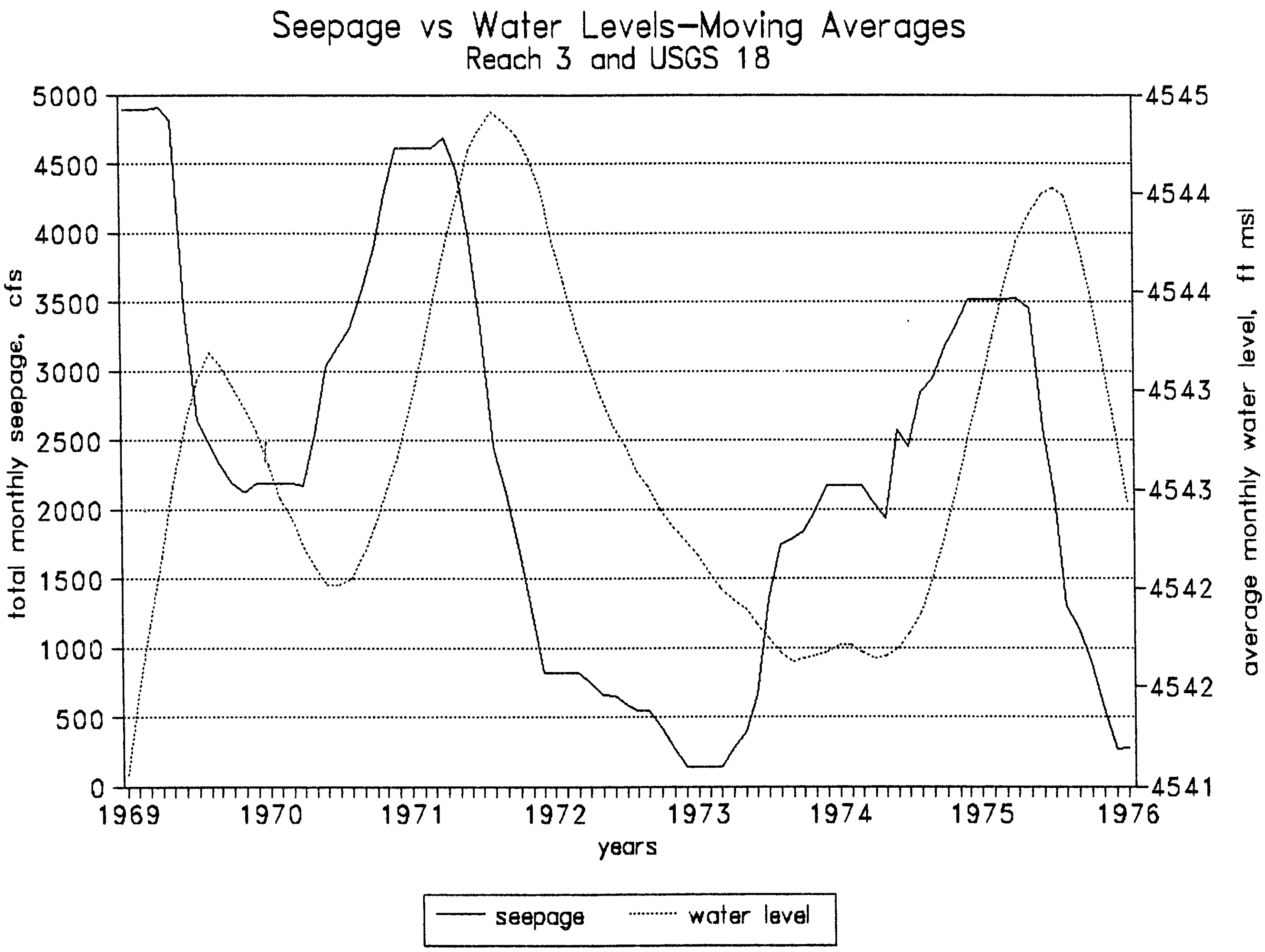
The original hypothesis, suggesting that there would be a correlation because the reach was northeast of the well and groundwater flow is southwest, was wrong. It is possible that seepage does impact the well, but not in any measurable manner using the methods in this study.

This attempted correlation was the only one performed in the study for reach 2. USGS 9 was the closest well to reach 2 of those chosen, and the obvious choice for study. Given the distance to the other two wells and the flow direction of groundwater, there were no other feasible choices for comparison. There are many wells located much closer to reach 2, and further study might reveal a strong correlation exists with some of them.

REACH 3 AND USGS 18

When the study wells were selected for these analyses, it was believed that the comparison of reach 3 and USGS 18 would adequately represent the system in the northern portion of the site. Using the same procedures previously described, the seepage and well data were averaged, with a 12-month moving average, and these moving average graphs are shown in figures 5.41 and 5.42. Although figure 5.41 depicts some peak-to-peak correlation during the first period of study, 1969-76, the regression analyses for this period yielded only a maximum r^2 of 0.61 for n=7. There was no significant correlation at all during the second period of study, 1983-87 (the maximum r^2 was 0.14 for n=8).

11 A



Seepage vs Water Levels—Moving Averages
Reach 3 and USGS 18
total monthly seepage, cfs
average monthly water level, ft msl
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4545
4544
4544
4543
4543
4542
4542
4541
1969
1970
1971
1972
1973
1974
1975
1976
years
seepage
water level

fig 5.41

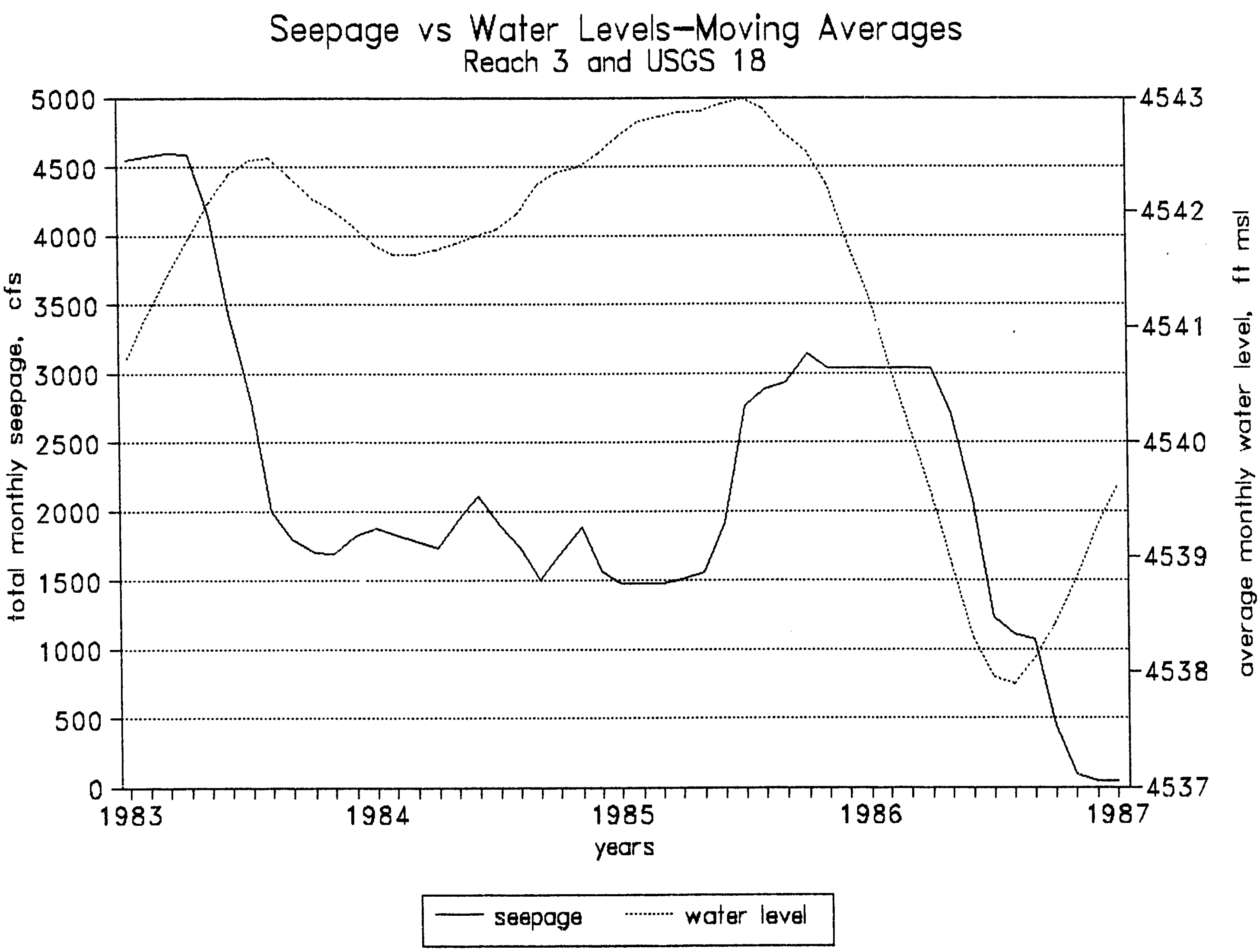

Seepage vs Water Levels—Moving Averages
Reach 3 and USGS 18
total monthly seepage, cfs
average monthly water level, ft msl
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4543
4542
4541
4540
4539
4538
4537
1983
1984
1985
1986
1987
years
seepage
water level

fig 5.42

One theory was postulated as to why there was at least a weak correlation during the first period but not the second. Regional groundwater flow is naturally to the southwest, but it has been documented as altering to the northeast under higher river flow conditions. USGS 18 is located at the far northeast end of reach three. The first period of time, 1969-76, was a high flow period, and thus seepage could have impacted the well by changing the groundwater flow direction. The second period, 1983-87, was a below average period, so groundwater flow most likely continued to the southwest and seepage had no impact, with correspondingly low correlation. From this analysis, it was presumed that seepage only affects the northern portion of the site during high flow conditions.

Comparison with Previous Work

No direct comparison between this study and others was possible since this was the first study of its kind for the site. However, results could be indirectly compared with Bennett's (1990) to determine if the same conclusions were reached regarding the connection between flow in the Big Lost River and groundwater levels. Nace and Barraclough (1952) did not compare seepage or flow to groundwater levels in any wells, as discussed earlier, and therefore no comparison can be made with their study.

Bennett (1990) noted that for his two study periods (July 1972 to July 1978 and July 1981 to July 1985), the first one experienced a net decline in groundwater levels and the second one a net increase. Although this study used slightly different study periods, Bennett's respective decreases and increases can be seen on any of the well hydrographs presented here. As has already studied in this report, and was noted by Bennett also, groundwater levels fluctuate consistently with changes in flow in the river. Bennett summarized his analysis of the correlation between groundwater and surface water by stating that two areas on the INEL site appeared to be most significantly affected by recharge from the river: just north of the Naval Reactors Facility (NRF) and southwest of the RWMC.

This current study again researched the area near the RWMC (USGS 9) and concluded that there is a strong seepage-groundwater level correlation for the area. The well selected for analysis near the NRF (USGS 18) was different than the two Bennett used (USGS 12 and 23), and more to the northeast. Results of the analyses showed some correlation during the first period of study but not during the second, possibly due to the fact that flow was practically nonexistent from 1983-1987 and thus would not affect groundwater. Bennett's second period of study was earlier than this study's and was during high river flow, which would affect groundwater much more. Bennett also noted that prominent groundwater peaks are seen in 1967, 1969, 1983 and 1984, years when very high flows were found in the river. These peaks can also be seen in the hydrographs presented in this report.

Chapter VI

Summary and Conclusions

Seepage from the Big Lost River can cause large fluctuations in both groundwater levels and the direction of groundwater flow in the Snake River Plain aquifer beneath the INEL. In turn, the paths and concentrations of radioactive waste in the groundwater can be altered. Some researchers have investigated seepage rates along the Big Lost River, and others have spent considerable time monitoring groundwater in the Snake River Plain aquifer. There has also been some limited research into the relationship between flow in the river and groundwater levels. However, no specific research has examined the correlation between seepage from the river and groundwater.

Research for this thesis initiated the investigation into the relationship between seepage and groundwater. Two parts were involved in the study. Seepage losses for both the spreading areas and reaches of the river were studied in part one, with a compilation of daily seepage records as results. Part two, the crux of the study, used the seepage records and compared them against water levels in some USGS wells. Results from the study demonstrated a strong correlation between seepage and groundwater levels.

To begin the study, daily seepage from the Big Lost River was identified and quantified, and a daily seepage record compiled for use in the second part of the study, comparing seepage and groundwater levels. For the defined river reaches, most of the daily seepage record was completed by applying the inflow-outflow method using the upstream and downstream gage records as data input. However, there were days in the study period when downstream flow exceeded upstream flow (13.8% of the time in reach 1, 11.2% in reach 2), and application of the inflow-outflow method was inappropriate. This required the use of an alternative method to calculate seepage.

To complete the set of daily seepage values for the river reaches, an equation that calculated seepage based on average flow in the reach was developed. A regression analysis was applied to derive this equation, using average reach flows as the independent variable (excluding those days when downstream flow exceeded upstream flow) and seepage as the dependent variable. Correlation coefficients for this analysis were not very high (r^2=0.40 in reach 1, r^2=0.38 in reach 2), and the approach did not meet all regression criteria, but it was nevertheless applied, because, despite the inadequacies of the approach, its use was required less than 14% of the time and therefore should not have introduced significant error into the seepage record.

A daily seepage record was also compiled for the spreading areas, because seepage from the spreading areas was very important in this analysis. The basins are in close proximity to the RWMC, and large volumes of water are allowed to flow in and seep out, so seepage can have a large impact on the groundwater. A simple inflow-outflow approach could not be applied in this case because, although inflow was measured by a stream gage, outflow was primarily seepage, and therefore not gaged. Instead, a routing analysis was applied, using the streamflow gage as inflow and some estimated daily seepage values for each of the four basins as the outflow. Estimated seepage values were based on an assumed one month complete drain time for all four basins. The study performed a sensitivity analysis on this assumption and found that one month was a reasonable time for the basins to drain, once they were completely full. From this routing analysis a daily seepage record was compiled.

The second, and most important, part of the study was the correlation between seepage and groundwater levels. Seepage and groundwater level hydrographs were compared on a monthly basis, since daily records of water levels were not kept for the wells examined. Correlations were examined between seepage and groundwater levels for the following areas: reach 1 and USGS 8; the spreading area and USGS 9; reach 1 plus the spreading areas and USGS 9; reach 2 and USGS 9; and reach 3 and USGS 18.

The objective of this analysis was to identify a time lag between seepage and groundwater, with groundwater levels fluctuating some time after seepage occurred. High correlations were found, using moving averages of total monthly seepage and average monthly water levels, between reach 1 and USGS 8 ($r^2=0.884$ at a time lag of 6 months), the spreading areas and USGS 9 ($r^2=0.937$ at 5 months), and the combined seepage from reach 1 and the spreading areas and USGS 9 ($r^2=0.94$ at 5 months). Very little to no correlation was found in the latter two study cases. For the first two above comparisons, the determination coefficients were both high for the moving averaged data, but the same did not hold true when comparing the raw monthly data. For reach 1 and USGS 8, the highest r^2 was 0.359, whereas for the spreading areas and USGS 9 the highest r^2 was 0.683. This illustrates what the regression on the moving averaged data did not: The seepage-groundwater level interaction is much stronger for the spreading areas. This would be expected because of the different seepage conditions (ponding versus flowing water), but it was not illustrated using just the moving averaged data.

Although this study identified a single parameter called time lag, and defined it as the time between a seepage event and the point when the event had an impact on the groundwater, it does not directly represent vertical travel time from ground surface to the groundwater basin. It is a lumped parameter that takes into account vertical and horizontal transmissivities throughout the soil strata, hysterisis along the capillary fringe, storativities, time of year, possible short circuiting between the ground surface and groundwater table, and potential pressure waves through the soil strata, among other parameters. There are a number of parameters lumped into the time lag, too many to examine for this study, which is why the time lag parameter was studied instead. It was a parameter used in the study to look for a correlation between seepage and groundwater levels.

Recommendations

This research was the first of its kind to study the correlation between seepage and groundwater levels. Future research will hopefully find use of the results. At the end of the study some thought was given to ways to improve the results.

Results from part one of the analysis were very acceptable when the inflow-outflow method was applied, but less so when the estimation techniques were required. A couple methods to improve the applied seepage-average flow correlation were considered but not explored. For the river reaches, the correlation between seepage and average flow might have been stronger and more representative if only those days when flow was found at both the upstream and downstream gage had been used in the analysis (for this research flow was not required downstream). Another approach might have been to divide the average flows and the respective seepage into percentile groups (for example, the lower 10 percent of average flows into one group, the second lowest 10 percent into another group, etc.), perform regressions on the separate groups, and accumulate a number of regression equations (10 in this example). Average flow could then be calculated for a reach and a specific equation applied to calculate seepage.

No matter how much the seepage-average flow equations are refined, they will never represent the real life seepage conditions. Average flow does represent flow depth and velocity, but not other factors including varying stream bank hydraulic conductivities, changing degrees of saturation, and fluctuating wetted perimeters. With time and equipment, seepage could be monitored throughout the reaches and more exact estimates determined. However, this would take large amounts of time and money, resources that were not available for this research.

To improve the seepage-groundwater level analysis, the time period could be shortened to a weekly or daily basis. This would provide more accurate results regarding the time lag, but would also require more frequent monitoring of select wells. A study of this magnitude would require large amounts of time to build up an acceptable well record to satisfy the hydrologic requirements.

Some valuable information was learned in this part of the study, including the fact that there did appear to be a relationship between seepage and average flow, and much more could be learned if more monitoring of conditions was done. It is hoped that the results of this study provide more of an understanding about the hydrologic system on the INEL site and furnished future researchers a base from which to continue study.

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