Report on

Kansas River Valley Groundwater Impact Investigations

for the

Regulatory Plan Commercial Sand and Gravel Dredging Kansas River

Kansas City District, Corps of Engineers
DACW41-86-D-0024

1986

85-809-4-003

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March 27, 1987

Department of the Army
Kansas City District, Corps of Engineers
700 Federal Building
Kansas City MO 64106-2896

Attention: Mr. Philip L. Rotert
Chief, Planning Division

Contract DACW41-86-D-0024
Delivery Order No. 3
Kansas River Valley
Groundwater Impact Investigations
B&McD Project 85-809-4-003

Gentlemen:

We present herewith a Report on Kansas River Valley Groundwater Impact Investigations in accordance with our Contract Delivery Order No. 3 dated May 30, 1986.

The report includes engineering investigations of groundwater impacts to five well fields and miscellaneous industrial and irrigation wells in the lower Kansas River Valley between Lawrence, Kansas and Kansas City, Kansas. Mr. Thomas A. Prickett of Consulting Water Resources Engineers, Urbana, Illinois, provided consultation with respect to the analyses of groundwater systems including instructions in the use of the Prickett-Lonnquist Aquifer Simulation Model used in the study.

We wish to thank the staff of Environmental Resources Branch Planning Division for their assistance provided during the course of this work. We remain ready to discuss the details of the report at your convenience.

Sincerely,

David H. Stous, P.E.
Groundwater Hydrologist

James W. Mellem, P.E.
Environmental Engineer

Frank L. Shorney, P.E.
Project Manager

STATE OF MISSOURI
FRANK
LaVERN SHORNEY
NUMBER
E-20261
REGISTERED PROFESSIONAL ENGINEER

DHS/FLS/JWM/gph

4800 EAST 63rd STREET, P.O. BOX 419173, KANSAS CITY, MISSOURI 64141-0173 • TEL: 816-333-4375 TWX:910-771-3059

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INTRODUCTION

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PURPOSE

The purpose of this report is to estimate the impact of lowering the channel bed of the Kansas River from 1, 3 and 5 feet between Eudora and Kansas City, Kansas on adjacent groundwater systems used by Water District No. 1 of Johnson County, Kansas, the Cities of Bonner Springs, Olathe and DeSoto, Kansas, the Sunflower Army Ammunition Plant and miscellaneous industrial and irrigation groundwater users. This report is prepared for use in the development of a regulatory plan for commercial sand and gravel dredging in the Kansas River by the Department of the Army, Kansas City District, Corps of Engineers.

SCOPE

This report includes:

- Collection of soil boring and well drilling logs and groundwater system information.
- Data reduction, analysis and plotting by computer.
- Development of groundwater system models to estimate groundwater level impacts in three river reaches.
- Estimation of impacts to five groundwater well systems and miscellaneous industrial and irrigation wells located along the Kansas River.
- Computation of costs to effect mitigation of impacts to groundwater well systems and miscellaneous wells.

SUMMARY

SUMMARY

Channel degradation has occurred in the lower reaches of the Kansas River in recent years which is believed attributable to commercial sand dredging operations. The U.S. Army Corps of Engineers has concluded that a regulatory plan should be developed to use as a guide for processing future dredging permits. This report will be used to assist in the development of a regulatory plan by identifying impacts of river degradation on alluvial groundwater users between Lawrence and Kansas City, Kansas.

GROUNDWATER SYSTEMS

Groundwater users which are investigated in this report for the effects of river degradation include Water District No. 1 of Johnson County, Kansas, the cities of Bonner Springs, Olathe and DeSoto, Kansas, the Sunflower Army Ammunition Plant and miscellaneous industrial and irrigation wells in the Kansas River alluvium. Groundwater systems for these users have the following features:

Groundwater System	Number of Wells	Total Well[1] Capacity (MGD)	Average[1] Annual Pumping (MGD)
W. D. No. 1 of Jo. Co., Kansas	21	10.6	2 to 5
Bonner Springs, Kansas	5	2.6	0.8
Olathe, Kansas	11	7.6	3 to 4
DeSoto, Kansas	4	1.8	0.4
Sunflower Army Ammunition Plant	12	2.1	2.0
Industrial Users	6	2.3[2]	---[3]
Irrigation Users	8	7.4[2]	---[4]

NOTES:
1. MGD denotes million gallons per day.
2. Authorized rate of diversion.
3. Authorized amount is 1,032 acre feet per year.
4. Authorized amount is 14,612 acre feet per year.

The geology of the Kansas River Valley in which the wells are located is largely influenced by glacial activity with the floodplain established by material erosion and deposition during the Pleistocene age. The valley floodplain is underlain by Pennsylvanian age bedrock primarily of limestone and shale layers. The floodplain alluvium generally consists of upper layers of fine silts and clays, intermediate layers of fine sands and lower layers of medium to coarse sands and gravels.

Groundwater hydrologists have long recognized the interrelationship between groundwater levels in the Kansas River alluvium and river stages. In recent years, river channel degradation (and the associated lowering of river water levels) has caused concern for the impact of declining groundwater levels on nearby groundwater users.

Typical well construction includes the use of steel casings which extend to depths of 45 to 80 feet into the valley alluvium with 13 to 25 feet of attached well screen. Well capacities generally range from 200 to 500 gallons per minute (gpm) and require periodic treatment with acid and phosphate solutions to maintain well capacity. Without treatment, mineral incrustations from dissolved chemicals in the groundwater form in the well screen and gravel pack and gradually reduce well capacity with time.

DATA COLLECTION AND ANALYSIS

Data collection for this investigation includes information on well construction details, geologic logs, well pump test data, well operation and maintenance records, and groundwater level records. Information is available from a number of entities including five major groundwater users, the Kansas Geologic Survey, the U.S. Geologic Survey, the Kansas Division of Water Resources, the Layne-Western Company and the U.S. Army Corps of Engineers. Groundwater level data in the lower Kansas River Valley of particular use in this investigation is included in a 1974 Kansas Geological Survey bulletin prepared by Stuart W. Fader.

A mathematical groundwater computer model, the Prickett-Lonnquist Aquifer Simulation Model (PLASM), is used in this investigation to relate the hydrological interaction of well fields, alluvial aquifers and the Kansas River. Three model areas are developed in the lower Kansas River Valley for five major groundwater users and are calibrated to establish various hydrogeologic parameters by matching historical groundwater levels. The calibrated models are used to determine projected groundwater levels for three river scenarios including Case 1 (1 foot degradation with associated river level decline), Case 2 (3 feet degradation with associated river level decline) and Case 3 (5 feet degradation with associated river level decline) at low river flow conditions of less than 1000 cubic feet per second discharge.

GROUNDWATER SYSTEM IMPACTS

Groundwater system impacts for individual well fields are determined using projected groundwater levels from the three computer models and manual computations using site-specific well operating data. In this analysis, the top of the well screen is assumed to be the minimum acceptable well pumping water level and specific capacity data is used to estimate pumping water levels and to determine the amount of reduced well discharge in each well field.

Because of the lack of well construction records, impacts for industrial and irrigation wells are determined by theoretical methods. Procedures include the assumption of probable well construction details at present river conditions which are compared with calculated drawdown conditions to determine impacts for each river degradation case.

General well field impacts caused by river degradation and associated river level declines include lower groundwater levels and, in several cases, reduced well yields. In all cases, lower groundwater levels will result in higher pumping heads and increased power costs. Reduced well yields will occur when drawdown intersects the top of the well screen because of lower groundwater levels and will result in additional costs to groundwater users.

Three alternatives for mitigating the impacts of various river degradation scenarios are investigated in this study. These alternatives include:

- Alternative No. 1: Modification of well field operation to produce additional groundwater to offset lost yield by using extra available well field capacity; or, operating affected wells with pumping water levels in well screens with additional well treatment to remove mineral incrustations in well screens and surrounding gravel pack and provision of additional pumping energy for well operation to offset lower groundwater levels.

- Alternative No. 2: Addition of replacement well(s) to offset lost well field capacity and provision of additional pumping energy for well operation to offset lower groundwater levels.

- o Alternative No. 3: Purchase of replacement water from nearby water purveyors to offset lost well field capacity and provision of additional pumping energy for well operation to offset lower groundwater levels (this procedure is assumed not applicable to irrigation wells because of high purchase water costs).

Impacts to groundwater users for various river degradation scenarios are shown in Table S-1 in terms of lost well capacity and cost estimates for various mitigation alternatives. Well capacity lost under present riverbed conditions and Case 1, 2 and 3 conditions at low river flow is based on the criteria that groundwater drawdown would not drop below the top of well screen for acceptable well operation. Several groundwater users currently experience pumping water levels below the top of the well screens at present riverbed conditions during low flow. When these conditions occur, pump discharge can be throttled on the affected wells to maintain desirable pumping water levels which results in reduced well yields.

Cost estimates shown in Table S-1 for additional pumping energy, modification of well field operation and purchase of replacement water are annual costs and cost estimates for addition of replacement well(s) are one-time capital costs. All mitigation cost estimates are based on net loss in well capacity which is the difference between well yields at present riverbed conditions at low flow and degraded riverbed conditions at low flow. All estimates are based on September, 1986 cost information.

Table S-1
River Degradation Impacts to Groundwater Users

Water District No. 1 of Johnson County, Kansas

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	0	0	0	0
Alternative Mitigation Costs:				
a. Additional Pumping Energy[2]	NA	$200	$600	$1,000
b. Modify Well Field Operation	NA	NR	NR	NR
c. Add Replacement Well(s)[4]	NA	NR	NR	NR
d. Purchase Replacement Water	NA	NR	NR	NR

City of Bonner Springs, Kansas

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	0	0	0	0
Alternative Mitigation Costs:				
a. Additional Pumping Energy[2]	NA	$100	$300	$500
b. Modify Well Field Operation	NA	NR	NR	NR
c. Add Replacement Well(s)[4]	NA	NR	NR	NR
d. Purchase Replacement Water	NA	NR	NR	NR

City of Olathe, Kansas

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	1002 gpm	1349 gpm	1754 gpm	2010 gpm
Alternative Mitigation Costs:				
a. Additional Pumping Energy[2]	NA	$ 400	$ 1,100	$ 1,800
b. Modify Well Field Operation	NA	$ 2,800	$ 6,900	$ 9,600
c. Add Replacement Well(s)[4]	NA	$112,000	$125,000	$237,000
d. Purchase Replacement Water	NA	$ 33,000	$ 42,000	$ 47,000

NOTES:

1. NA denotes not applicable; present or baseline reference condition.
2. Required for all mitigation alternatives.
3. NR denotes alternative not required.
4. Replacement well(s) are one-time capital costs.

Table S-1 (continued)
River Degradation Impacts to Groundwater Users

City of DeSoto, Kansas

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	249 gpm	273 gpm	380 gpm	513 gpm
Alternative Mitigation Costs:				
a. Additional Pumping Energy[2]	NA	$ 100	$ 200	$ 300
b. Modify Well Field Operation	NA	$ 1,200	$ 2,000	NF
c. Add Replacement Well(s)[4]	NA	$112,000	$112,000	$112,000
d. Purchase Replacement Water	NA	NF	NF	NF

Sunflower Army Ammunition Plant

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	0	0	0	0
Alternative Mitigation Costs:				
a. Additional Pumping Energy[2]	NA	$ 300	$ 900	$1,500
b. Modify Well Field Operation	NA	NR	NR	NR
c. Add Replacement Well(s)[4]	NA	NR	NR	NR
d. Purchase Replacement Water	NA	NR	NR	NR

Miscellaneous Industrial and Irrigation Wells

Item	Present	Case 1	Case 2	Case 3
Well Capacity Lost:	156 gpm	272 gpm	604 gpm	1048 gpm
Alternative Mitigation Costs:				
a. Additional Pumping Energy[6]	NA	N	N	N
b. Modify Well Field Operation	NA	$ 3,600	$ 4,800	$ 2,400[7]
c. Add Replacement Well(s)[4]	NA	$336,000	$336,000	$461,000
d. Purchase Replacement Water	NA	NF	NF	NF

NOTES:
1. NA denotes not applicable; present or baseline reference condition.
2. Required for all mitigation alternatives.
3. NF denotes alternative is not feasible.
4. Replacement well(s) are one-time capital costs.
5. NR denotes alternative not required.
6. N denotes neglible additional power requirements.
7. Cost does not include all wells because modification of operation is not feasible for all wells.

* * * * *

PART I—BACKGROUND DATA

PART I

BACKGROUND DATA

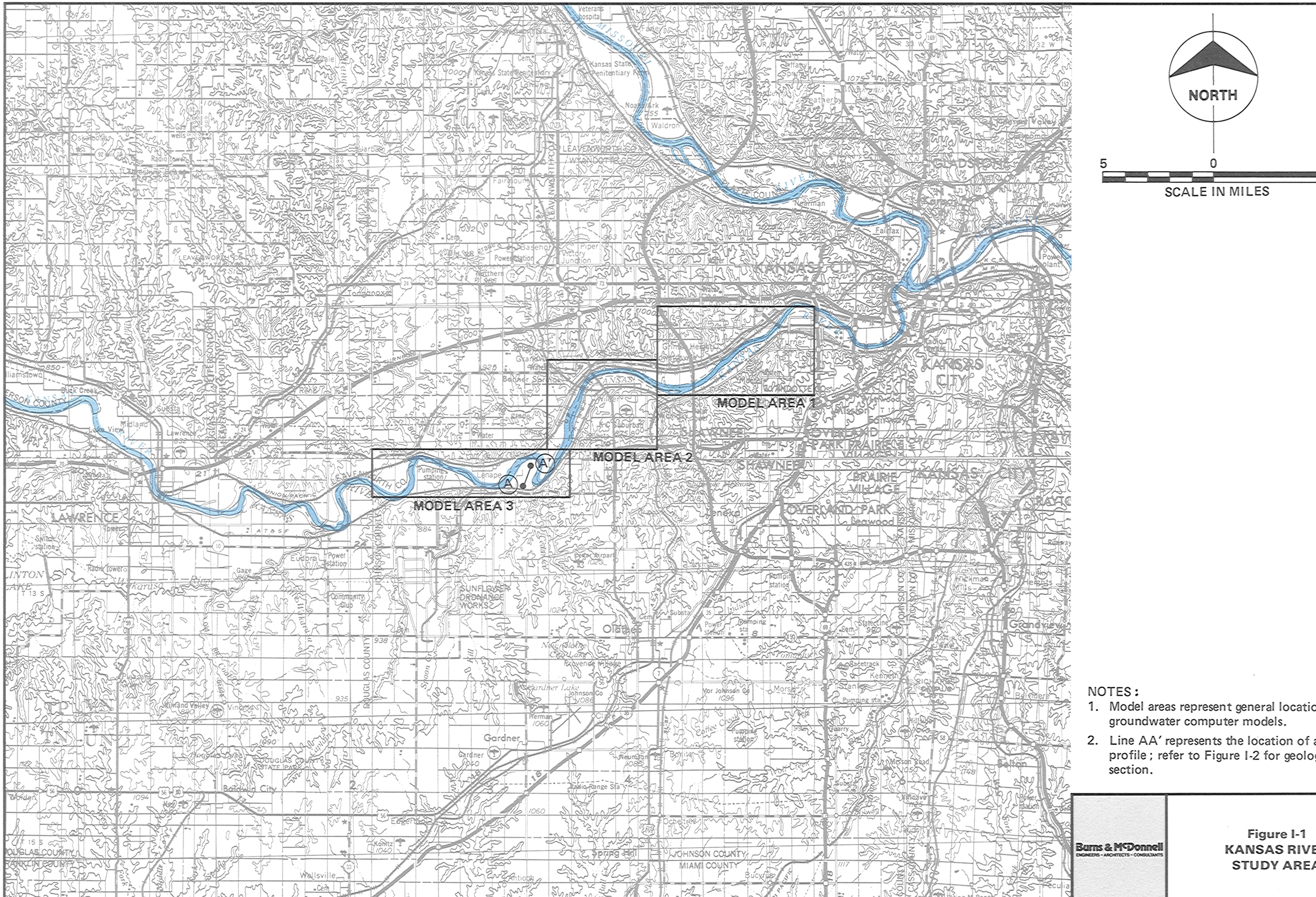
A. GENERAL

This report section discusses geology of the Kansas River Valley, degradation of the lower Kansas River and groundwater users which obtain groundwater from the Kansas River alluvium. The general location of the study area is along the lower Kansas River between Lawrence, Kansas and Kansas City, Kansas as shown in Figure I-1.

B. KANSAS RIVER VALLEY GEOLOGY

The Kansas River Valley contains groundwater in valley-fill deposits and in the underlying Pleistocene Age glacial drift. Valley sediments vary from locally derived limestone pebbles and cobbles near bedrock to brown-gray arkosic sand and gravel grading to fine sand with silt and clay near the surface. Upper deposits are predominantly Wisconsian Age glaciation deposits with some recent alluvial materials.

Glaciation during the Kansas stage of the Pleistocene Age enlarged the Kansas River Basin and caused considerable entrenchment of the Kansas River below its earlier base level. The river valley generally marks the southern limits of the Kansas glacial advance. Most of the deposits in the study area range in thickness from about 40 to 70 feet with the upper 35 to 45 feet consisting of material similar to the sediment being transported by the Kansas River. The depth of alluvium is over 150 feet in some of the buried channels downstream of the study area.



NOTES:
1. Model areas represent general locations of groundwater computer models.
2. Line AA' represents the location of a geologic profile; refer to Figure I-2 for geologic cross section.

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Figure I-1
KANSAS RIVER
STUDY AREA

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

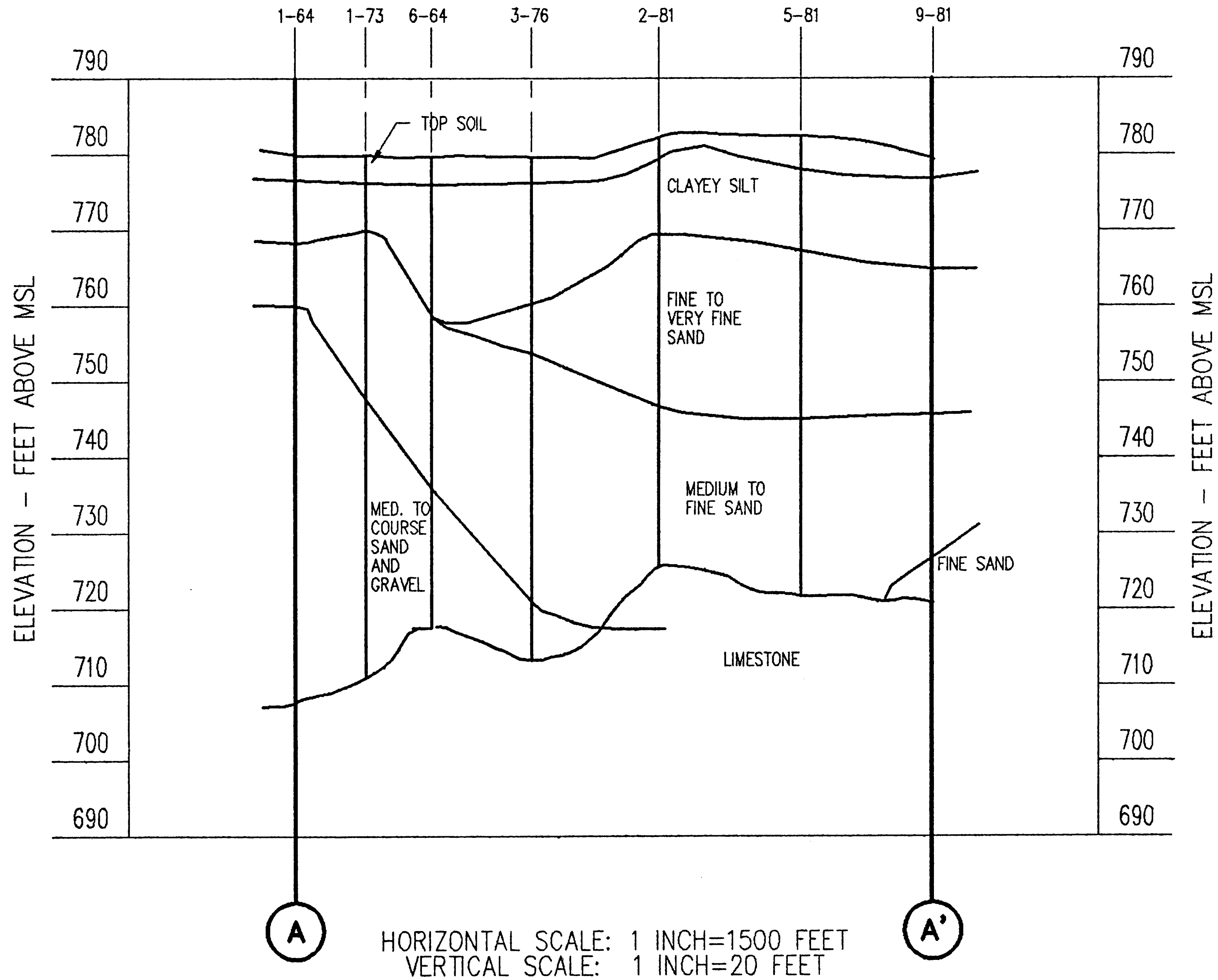
The valley is contained in bedrock of Pennsylvanian age. This bedrock occurs in uniformly alternating sequences of shale, limestone and sandstone termed "cyclothems." Limestone and shale are the predominant bedrock units.

The valley of the Kansas River is unusual in that its widest portion is not near the mouth at Kansas City but near River Mile 120 (near Topeka, Kansas) where the width is approximately 3.5 miles. The narrowest point between Kansas City and Lawrence is at Kansas City, Kansas near R.M. 10.5 where the valley is 0.9 mile wide. The valley ranges in width from 1.1 to 1.8 miles throughout the study area. A typical geological cross section of the Kansas River valley is shown in Figure I-2.

C. <u>KANSAS RIVER CHANNEL DEGRADATION</u>

Groundwater hydrologists have long recognized the interrelationship between groundwater levels in the Kansas River alluvium and river stages. In recent years. river channel degradation (and associated lowering of river water levels) has caused concern for the impact of declining groundwater levels on nearby groundwater supplies used by municipalities, industries and irrigators.

Recharge from local precipitation and pumping from wells also have significant influence on the groundwater system. In general, the water table is above the river water surface and contributes to river flow. However, when well pumpage lowers the groundwater level, the river contributes water to the groundwater system.



NOTES:

1. REFER TO FIGURE I–1 FOR LOCATION OF GEOLOGIC CROSS SECTION AA'.

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Figure I-2
GENERALIZED GEOLOGIC PROFILE
(SECTION AA[1])

River level declines between DeSoto, Kansas (R.M. 24) to Turner Bridge (R.M. 10) are shown in Figure I-3 for data obtained in 1947, 1962 and 1977. The declining river stage elevation for a constant 1000 cfs discharge in the Kansas River at the Bonner Springs gauge is shown in Figure I-4. Because the amount of river bed degradation near the gauge site at Bonner Springs, the gauge had to be moved to the bridge at DeSoto, Kansas in 1973.

Profiles of groundwater in valley-fill deposits for several dates are shown in Figure I-5. Cross-section data near the gauge at Bonner Springs shows recharge occurs from the river to the groundwater system when groundwater levels are lowered by well pumpage or when river stages are higher than groundwater levels. The declining groundwater profiles shown in Figure I-5 at the Bonner Springs gauge (now abandoned) are for different river flow rates. The general slopes of all profiles show the water table flowing toward the river. Alluvium groundwater is therefore assumed to be replenished or recharged by infiltration of precipitation and by groundwater flowing from the valley walls into the valley. Because the various profiles are essentially parallel and appear to closely follow the river stage, an extremely good hydrologic relationship is believed to exist between the river and the groundwater system.

D. GROUNDWATER USERS

Groundwater users which will be impacted by declining river water and associated groundwater levels in the lower Kansas River Valley include Water District No. 1 of Johnson County, Kansas, the cities of Bonner Springs, Olathe, and DeSoto, Kansas, the Sunflower Army Ammunition Plant

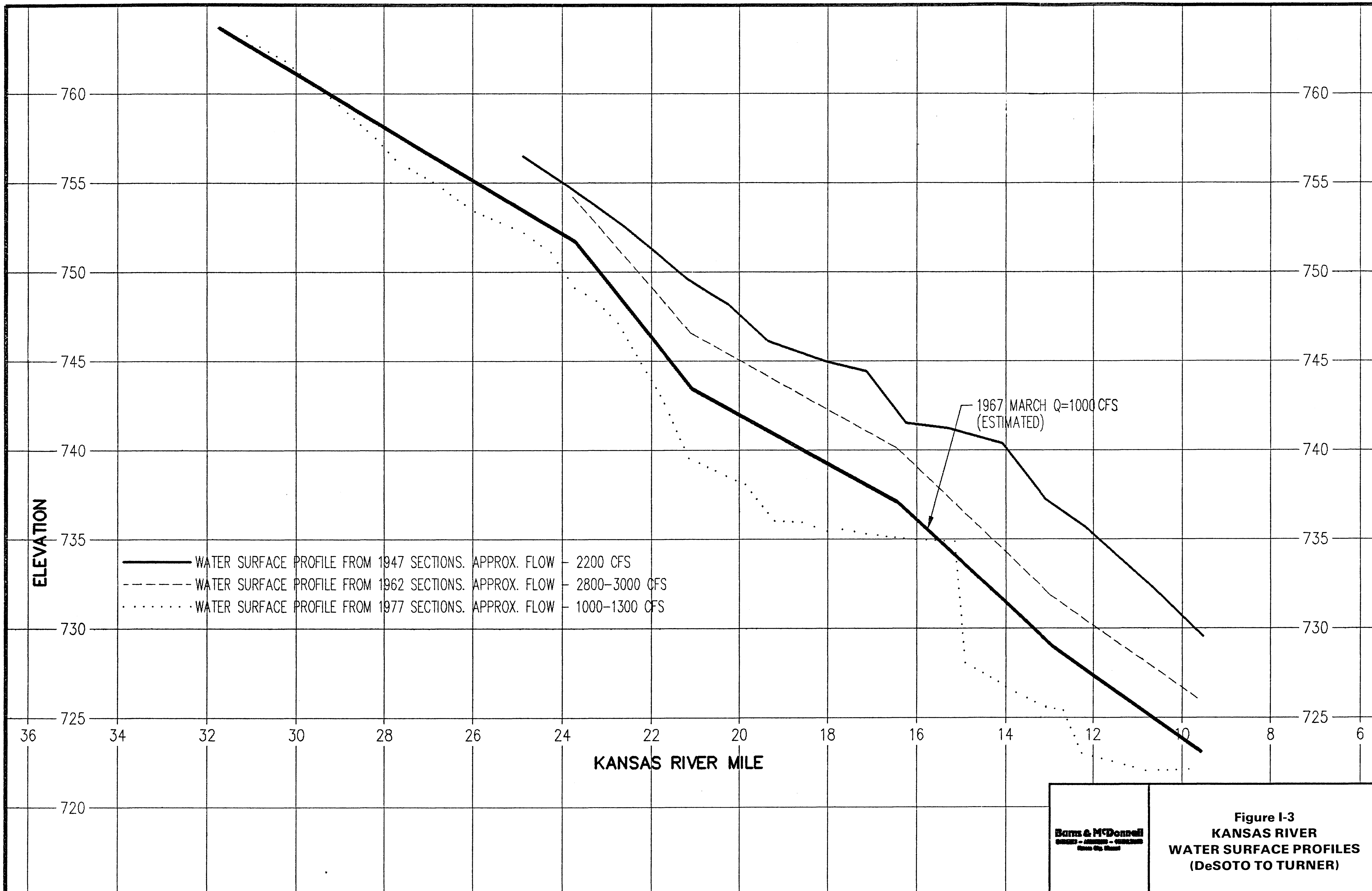
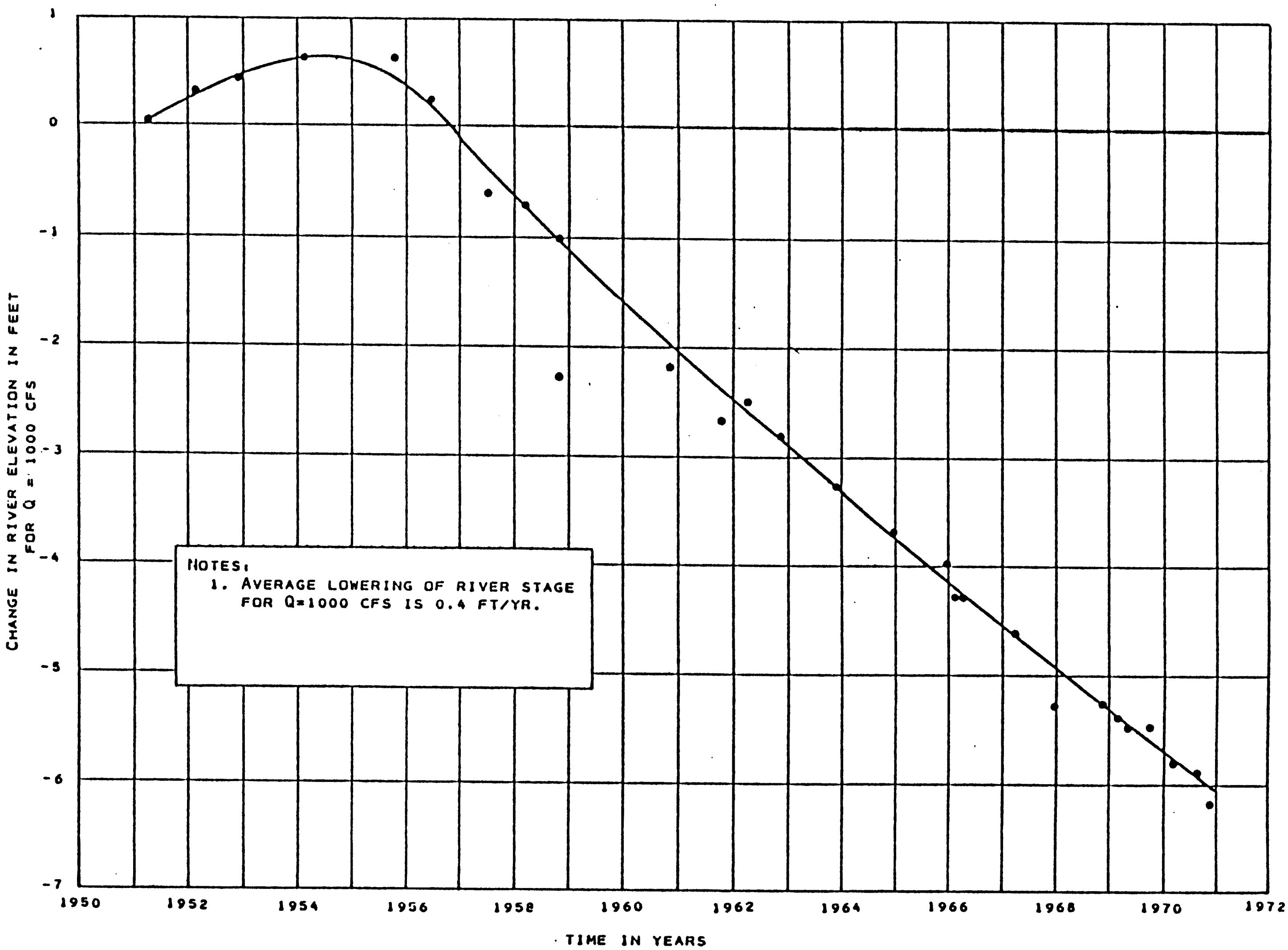


Figure I-3
KANSAS RIVER
WATER SURFACE PROFILES
(DeSOTO TO TURNER)



REDUCTION IN KANSAS RIVER ELEVATION AT BONNER SPRINGS, KANSAS FOR Q = 1000 CFS (1952-1972)

NOTES :

1. Graph from McCullen Groundwater Report for City of Olathe, 1981.

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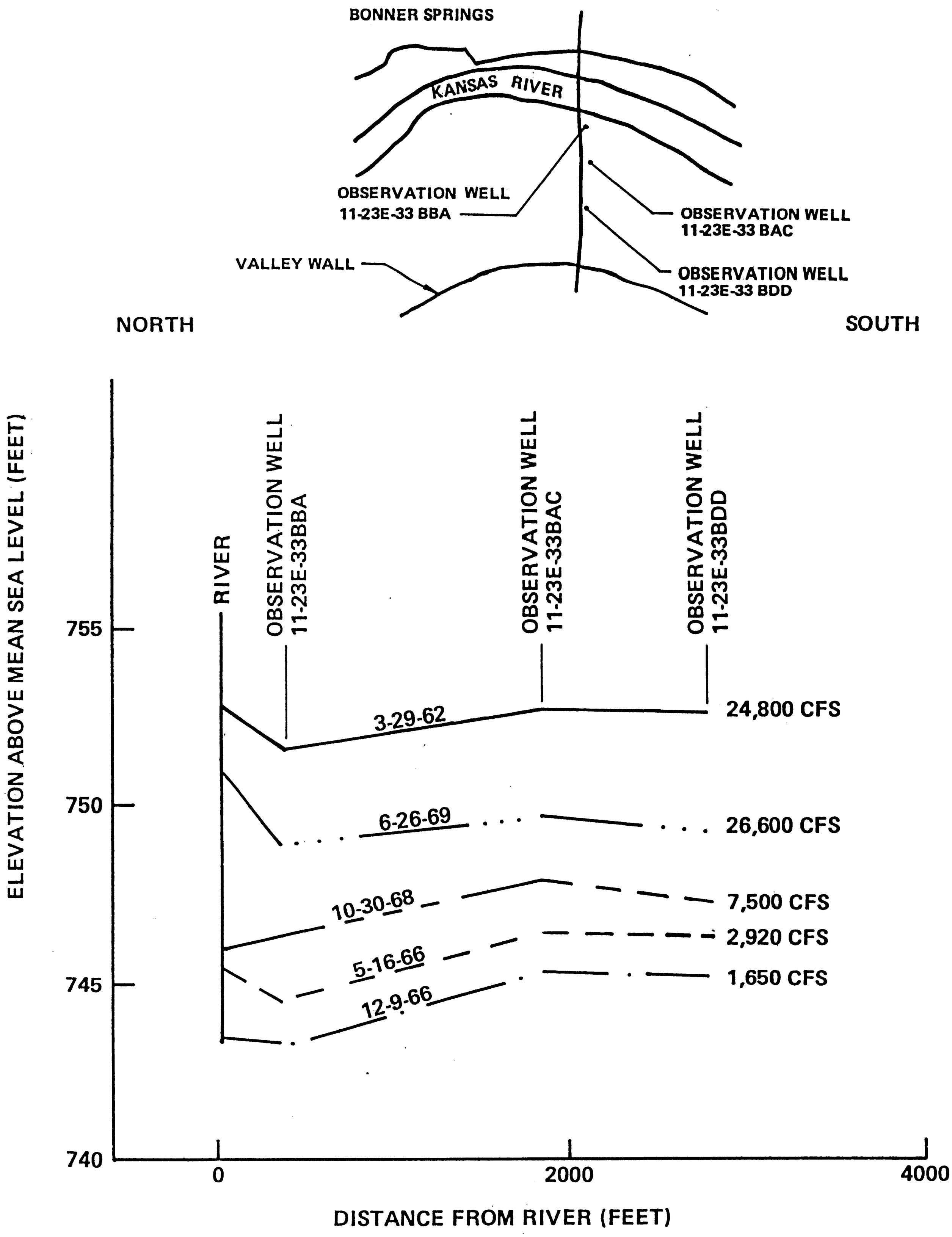
Figure I-4
ELEVATION OF CONSTANT 1000 CFS DISCHARGE BONNER SPRINGS, KANSAS



NOTES :
1. Information from Fader's 1974 work.

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Figure I-5
GROUNDWATER PROFILES NEAR BONNER SPRINGS, KANSAS

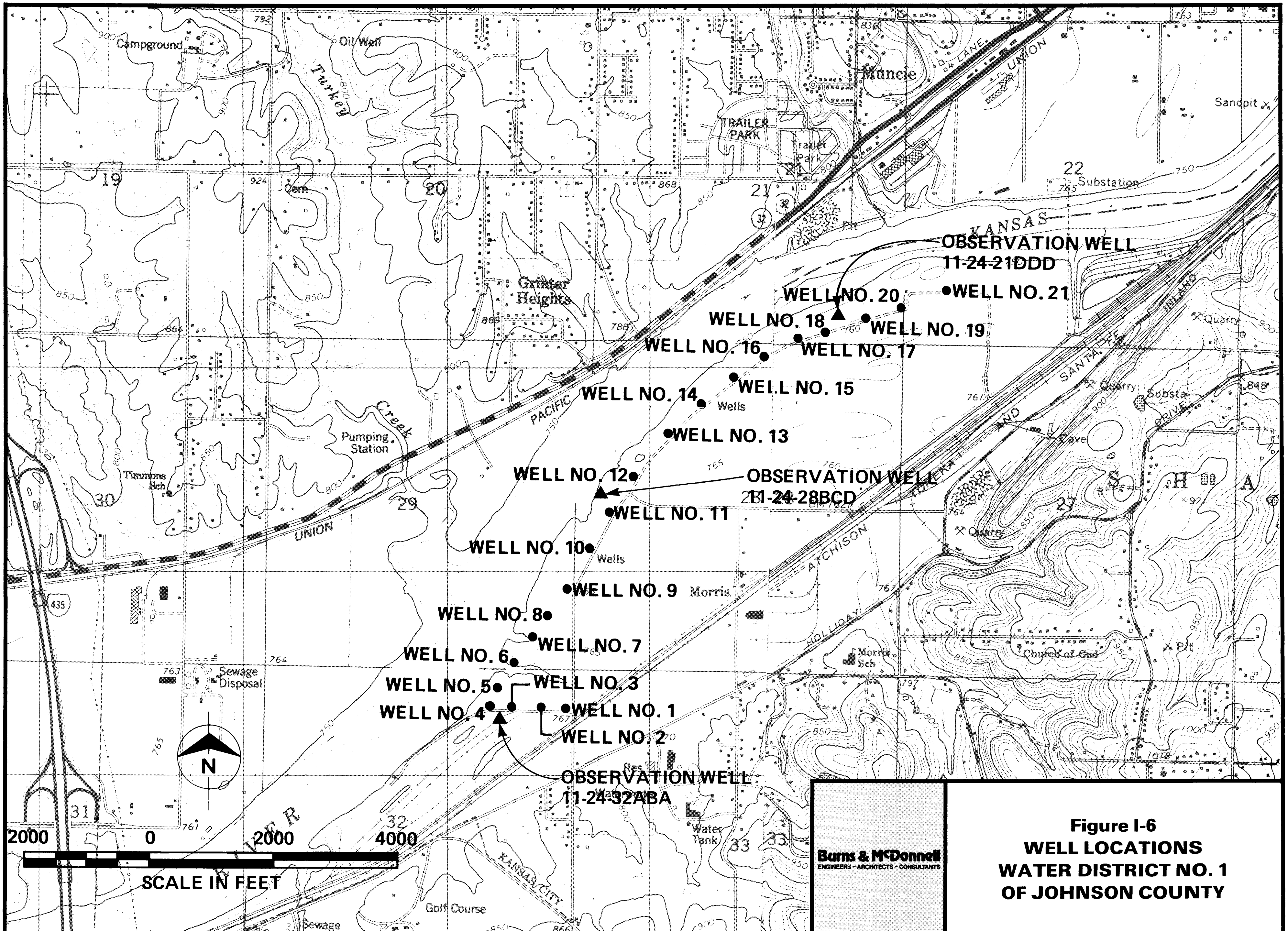


Figure I-6
WELL LOCATIONS
WATER DISTRICT NO. 1
OF JOHNSON COUNTY

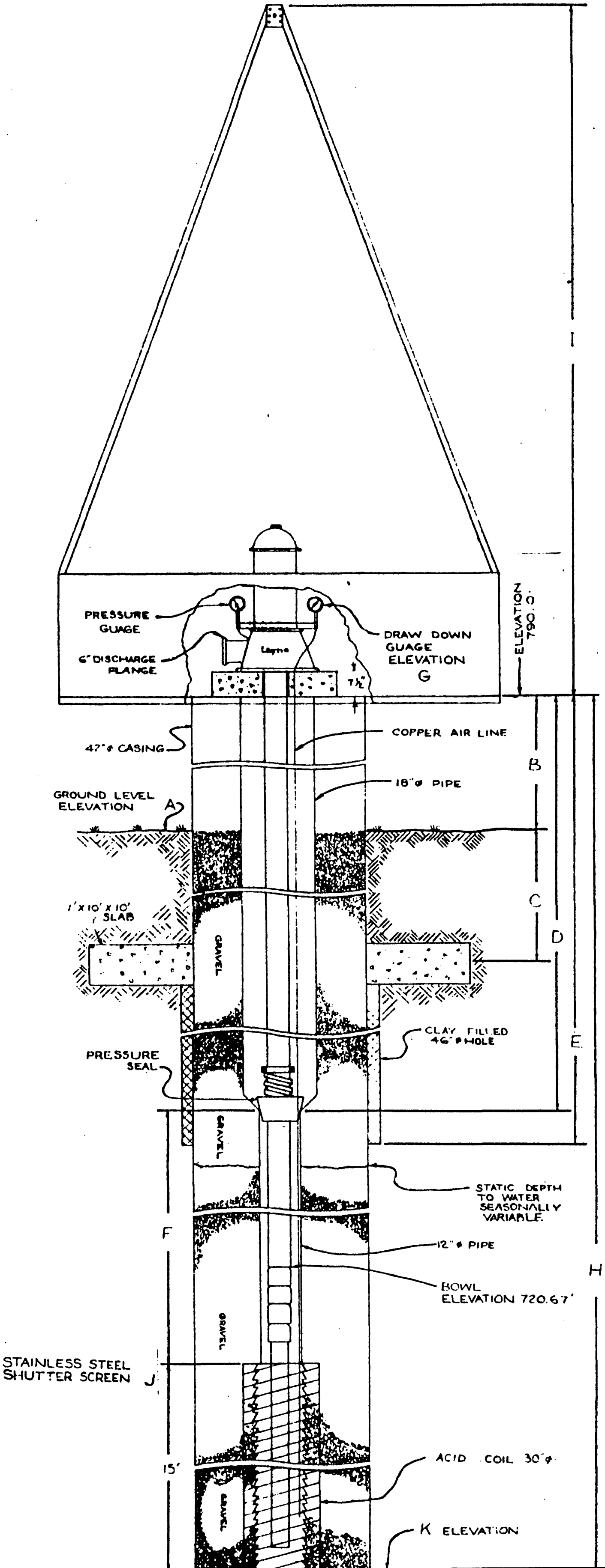
USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

The wells have depths ranging from 55 to 72 feet. Upper soils in the well field consist of silty clays, silts and fine sands to depths of about 7 to 21 feet and underlying materials consist of medium to coarse sands and fine gravels near bedrock. Bedrock consists of limestone with shale seams.

Typical well construction details are shown in Figure I-7. The first ten wells were installed circa 1956 and the last eleven were installed circa 1965. Well screens are 12 inches in diameter in the early wells and 18-inches in diameter in the later wells. All wells have screen lengths of 10 feet.

c. Groundwater Pumpage

Groundwater pumpage per year in million gallons (MG) and power consumption in kilowatt hours (kwh) for the well field over the last five years are shown in Table I-1. In 1985, groundwater usage declined 66 percent when the water district's new Missouri River supply facilities became operational. Prior to the use of the Missouri River supply, groundwater pumpage furnished 20 to 25 percent of the water district's total raw water needs. Groundwater pumpage is now approximately 7 percent of total raw water supply and is expected to remain at this quantity for the next several years.



WELL DIMENSIONS

WELL NO.	A	B	C	D	E	F	G	H	I	J	K
1	764.7'	23.3'	6'	45.6	55.37'	32.8'	792.13'	93.29'	18'	12"ϕ x 10' LONG	696.7'
2	765.1'	24.9	6'	45.6	55.0'	32.1'	792.13'	93.42'	18'	12"ϕ x 10' LONG	700.5'
3	765.5'	24.5'	6'	45.6'	54.33'	29.9'	792.13'	90.54'	18'	12"ϕ x 10' LONG	699.5'
4	766.0'	24.0	6'	45.6'	53.13'	34.4	792.13'	94.94'	18'	12"ϕ x 10' LONG	695.1'
5	767.7'	22.3	6'	45.6'	52.24'	33.5'	792.13'	94.08'	18'	12"ϕ x 10' LONG	695.8'
6	767.3'	22.7'	6'	45.6	51.50'	35.7'	792.13'	92.31'	18'	12"ϕ x 10' LONG	697.7'
7	762.8'	27.2'	6'	45.4'	56.50'	30.3'	792.13'	90.75'	18	12"ϕ x 10' LONG	699.3'
8	764.0'	26.0'	6	45.6	55.75'	30.3'	792.13'	90.92'	18	12"ϕ x 10' LONG	699.1'
9	764.4'	25.6	6'	45.4'	55.81'	31.4'	792.13'	91.80'	18	12"ϕ x 10' LONG	699.4'
10	765.8'	24.2'	6'	45.9'	55.00'	31.1'	792.13'	92.10'	18'	12"ϕ x 10' LONG	698.8
11	766.1'	24.9	6'	46.5'	54.0'	27.5'	790.50'	89.0'	24'	18"ϕ x 10' LONG	701.0'
12	766.3'	24.7'	6'	46.0'	53.7'	31.6	790.50'	88.6'	24'	18"ϕ x 10' LONG	701.4'
13	762.2	27.8	6'	44.4'	57.8'	32.0'	790.50	90.17'	24'	18"ϕ x 10' LONG	698.6'
14	765.8	24.2'	6'	46.4'	54.2'	27.7'	790.50	87.9'	24'	18"ϕ x 10' LONG	700.9'
15	765.8'	24.2'	6'	43.1'	54.2'	32.3'	790.50'	89.1'	24'	18"ϕ x 10' LONG	699.6'
16	767.5'	22.5'	6'	43.0'	52.5'	34.1'	790.50'	90.9'	24'	18"ϕ x 10' LONG	697.9'
17	765.4'	24.6'	6'	45.5'	54.6	31.5'	790.50'	90.8'	24'	18"ϕ x 10' LONG	698.0'
18	762.6'	27.4'	6'	44.3'	57.4	31.1'	790.50'	89.1'	24'	18"ϕ x 10' LONG	699.6'
19	761.1	28.9'	6'	44.0'	58.9'	29.0'	790.50'	86.8'	24'	18"ϕ x 10' LONG	702.0'
20	757.7'	32.3'	6	52.0'	62.3'	21.0'	790.50'	86.8'	24'	12"ϕ x 10' LONG	702.0'
21	758.7'	31.3'	6'	43.5'	61.3	29.6	790.50'	86.3	24'	18"ϕ x 10' LONG	701.9'

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Figure I-7
WELL CONSTRUCTION DETAILS
WATER DISTRICT NO. 1
OF JOHNSON COUNTY, KANSAS

Table I-1

W.D. No. 1 OF JOHNSON COUNTY, KANSAS
GROUNDWATER PUMPAGE

Year	Pumpage Per Year (MG)	Pumpage Per Day (MG)	% Change	Annual Power Consumption (kWh)
1981	1,789	4.90		1,397,400
1982	1,597	4.38	-10.6	1,227,600
1983	2,502	6.85	+56.4	1,578,000
1984	2,056	5.63	-17.8	1,581,000
1985	699	1.92	-65.9	363,600

d. Operation and Maintenance

Wells in the well field, like others in the Kansas River Valley, experience reduced pumping capacities with time (or reduced specific capacity measured in well yield per foot of drawdown) because of chemical or biological scales which form in the well screen and surrounding gravel packs when water is pumped from the aquifer. These scales may consist of calcium carbonate, iron or iron bacteria and manganese deposits. When scale accumulations cause unacceptable well performance, the wells are given acid and phosphate treatment. Such treatment usually increases well capacity, but full, original capacity is normally not recovered.

Typical treatment of wells in the Kansas River alluvium consists of multiple applications of acid and phosphate solutions. The acid solution is used to dissolve screen incrustations and is diffused by well surging techniques into the aquifer to dissolve chemical precipitation from the well formation. After surging, acid is pumped out and replaced by a phosphate solution. The phosphate solution is used to break up incrusting materials and to disperse the materials so they can be pumped out of the well. The phosphate solution also serves to break down any clay or silt which may have accumulated and clogged the screen or formation. Chlorine is usually added to the phosphate solution to disinfect the well to destroy any bacteria that may be present.

After treatment, the well is tested and specific capacity is calculated to determine the effectiveness of the treatment. Additional well treatment may be undertaken depending on the results of the test. Although treatment is a proven method to increase well capacity, it is not successful in all cases. Some wells do not respond to treatment because of local aquifer conditions, previous well maintenance, or a combination of both. Other wells respond favorably to treatment and some wells may actually be treated to obtain higher specific capacities than originally developed. These higher specific capacities result from the removal of fine materials during the treatment process which permits more efficient water flow from the formation to the well.

For the last 10 to 15 years, the water district has treated approximately one-third of the wells every spring and fall which results in the treatment of each well about every 18 months. Treatment costs typically vary from $3,000 to $3,200 per well and are paid from an annual budgeted amount of $50,000. All wells are in the treatment program except for Well No. 9 which has failed to respond to treatment methods.

Specific capacity data for the wells are shown in Table I-2. Specific capacities of individual wells after treatment range from 50 percent to 130 percent of original values. The average specific capacity of all wells has declined to 74 percent of original values.

Table I-2

WATER DISTRICT No. 1 OF JOHNSON COUNTY, KANSAS
WELL SPECIFIC CAPACITY

Well No.	Capacity[1] (gpm)	Specific Capacity Original	Specific Capacity After Last Treatment	Specific Capacity % of Original
1	659	165	214	130
2	877	150	161	107
3	730	164	169	103
4	530	171	146	85
5	618	195	214	110
6	550	141	90	64
7	496	122	89	73
8	439	131	65	50
9	---	---	---	---
10	330	123	70	57
11	156	93	68	73
12	242	79	51	65
13	202	80	48	60
14	314	89	56	63
15	142	92	48	52
16	339	---	---	---
17	136	129	84	65
18	71	109	69	63
19	59	97	49	51
20	152	89	74	83
21	107	114	70	61
Average Specific Capacity for All Wells:				74%

NOTES:
1. GPM denotes gallons per minute.
2. Specific capacity is defined as well yield (gpm) per foot of drawdown.

The water district reports very few problems with the wells and are generally satisfied with the service they provide. With the use of the new Missouri River supply, the wells are now used primarily during the winter months to blend warm groundwater with cold riverwater. This blending increases the temperature of the combined raw water source and reduces chemical costs and icing problems in the treatment basins. During nonwinter months, the wells are operated on a rotating basis to keep equipment exercised and in good working condition.

2. BONNER SPRINGS, KANSAS

a. Overview

The City of Bonner Springs, Kansas obtains groundwater from the Kansas River alluvium as its sole source of raw water for the municipal water system. The water system serves a city population of 6200 and provides wholesale water to Rural Water District No. 7 in Leavenworth County, Kansas.

b. Well System

The City's well field includes 5 wells along the Kansas River near R.M. 20 as shown on Figure I-8. Average daily production from the well field is approximately 0.8 MGD.

Wells in the well field have depths ranging from 70 to 80 feet. Upper alluvial material consists of 40 to 50 feet of gray and brown clay, silty clay and fine sand and underlying alluvial

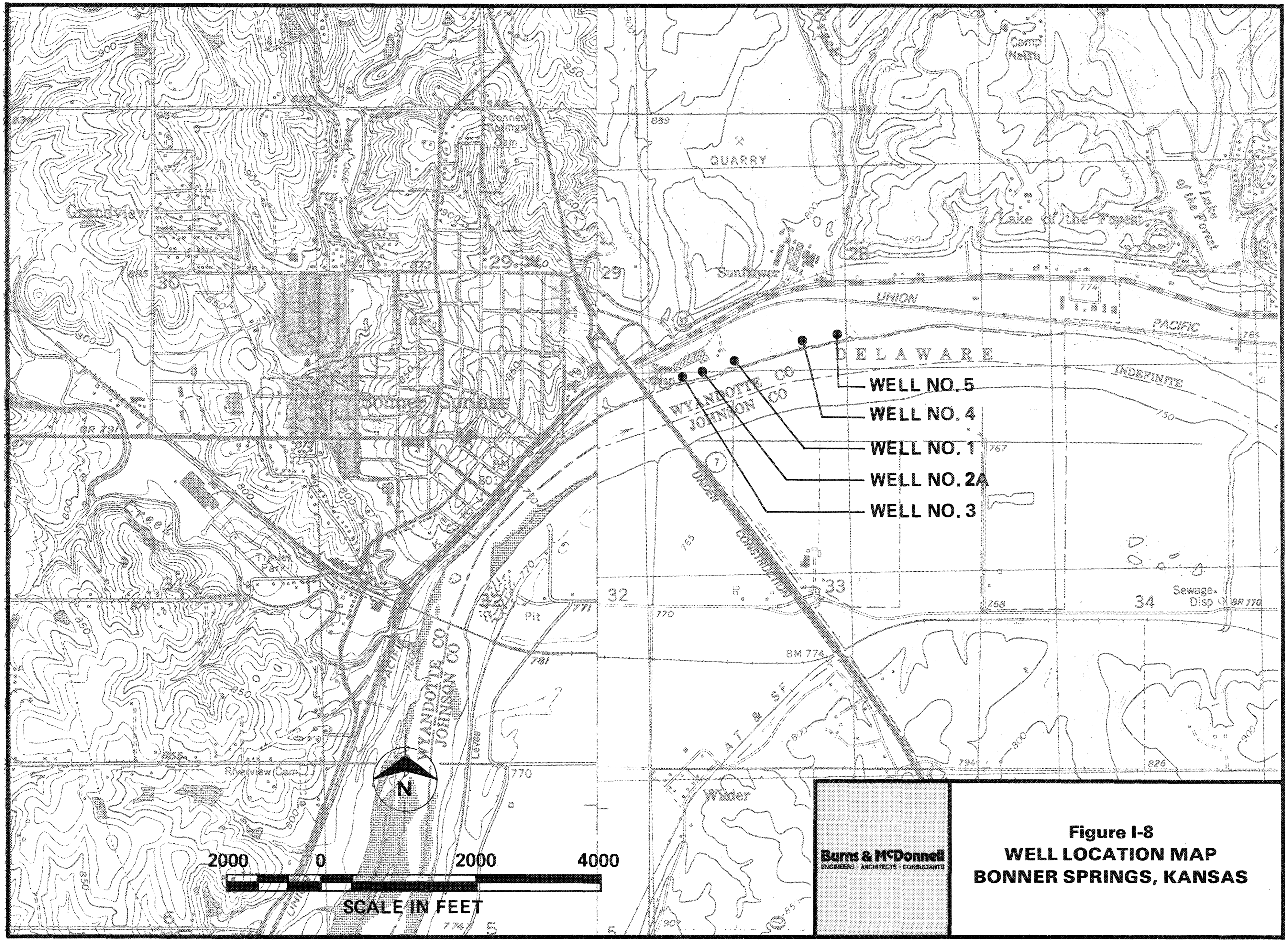

Figure I-8
WELL LOCATION MAP
BONNER SPRINGS, KANSAS

material consists of medium sand, coarse sand and gravel with occasional cobbles above bedrock.

Typical construction details for the five wells are shown in Figure I-9. The first well was constructed in 1951 and the last two wells were constructed in 1980. The last two wells are about 80 feet deep and have 13 to 15 feet of 16-inch diameter screen. The first three wells have gravel-packed screens and the last two wells are naturally developed in the aquifer formation.

c. Groundwater Pumpage

Groundwater pumpage from the well field for the last five years is shown in Table I-3.

Table I-3

BONNER SPRINGS, KANSAS
GROUNDWATER PUMPAGE

	Per Year (MG)						
	Well Number						Per Day
Year	1	2A	3	4	5	Total	(MG)
1981	30.5	28.6	26.4	126.1	46.0	257.6	0.71
1982	17.1	0.01	12.8	203.0	12.9	245.8	0.67
1983	44.5	1.0	0.1	221.5	---	267.1	0.73
1984	31.4	1.2	23.5	34.0	206.1	296.2	0.81
1985	2.5	9.2	13.0	91.6	171.3	287.6	0.79

d. Operation and Maintenance

The City recently experienced some operational problems with the new wells (Nos. 4 and 5) which were constructed in 1980. Sand was being pumped from the wells and the pumps required

WELL DATA

Well	Land Surface Elevation (feet USGS)	Top of Screen (feet USGS)	Length of Screen (feet)	Type Pump	Well Diameter
1	785.0	719.0	17	Vertical Turbine	12''
2A	785.0	720.0	20	Submersible	16''
3	785.0	719.0	17	Vertical Turbine	12''
4	785.0	715.0	15	Submersible	16''
5	785.0	714.0	12	Submersible	16''

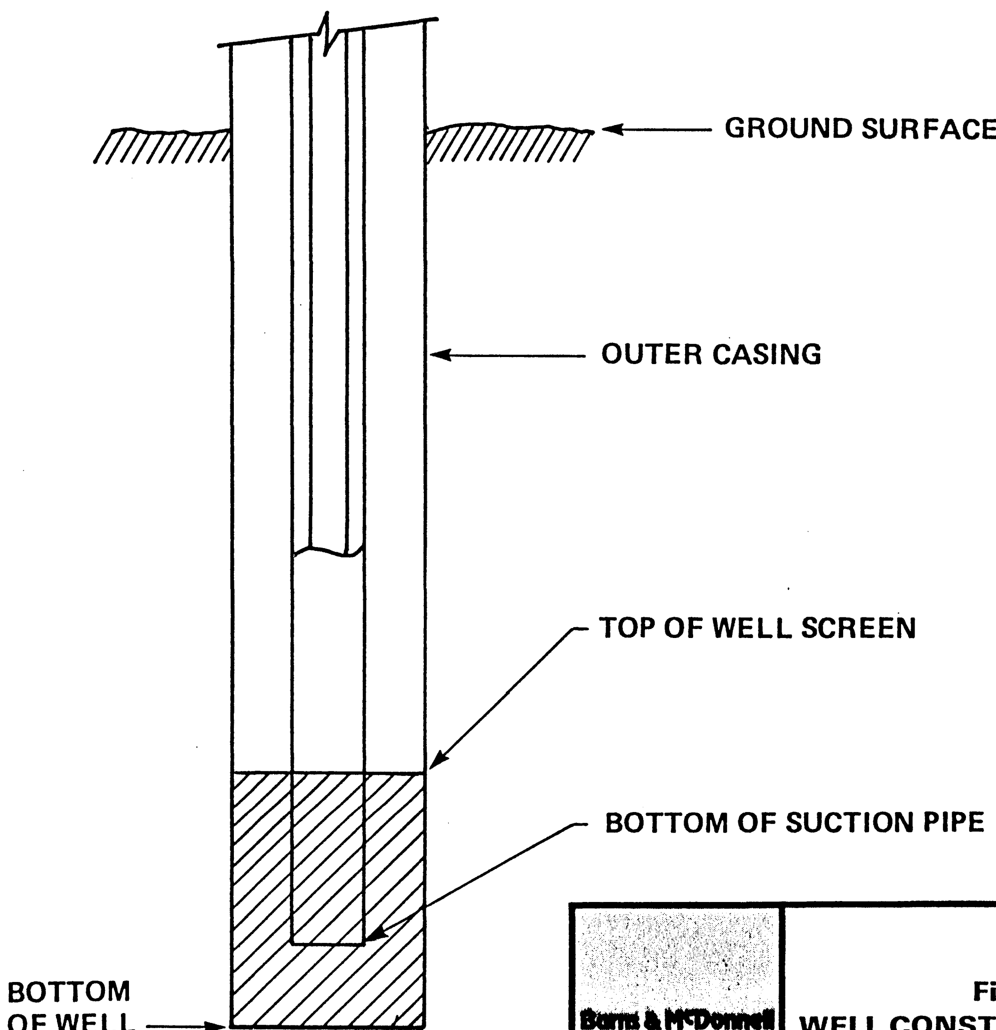

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Figure I-9
WELL CONSTRUCTION DETAILS
BONNER SPRINGS, KANSAS

replacement. An engineering consultant is presently investigating these problems for the City.

The City repairs and maintains the wells in the well field as problems arise. Wells are treated when well production capacity declines. None of the wells are treated at regularly scheduled intervals.

3. OLATHE, KANSAS

a. Overview

The City of Olathe, Kansas receives raw water from two sources, including surface water from Lake Olathe and groundwater from the Kansas River alluvium, and purchases treated water from Water District No. 1 of Johnson County, Kansas. The City provides treated water to city residents, Rural Water Districts 1, 3, 5, 6 and 7 and the City of Edgerton. Kansas. The City had a population of 47,000 in 1985 and has been one of the fastest growing communities in the metropolitan area.

b. Well System

The City's well field includes 11 wells on a 70 acre land tract along the Kansas River near R.M. 28 as shown in Figure I-10. Average annual production from the well field is 3 to 4 MGD.

Wells in the well field have depths ranging from 51 to 66 feet. Upper alluvial material includes 8 to 20 feet of clayey silt, silt and sand and underlying materials include 30 to 40 feet of

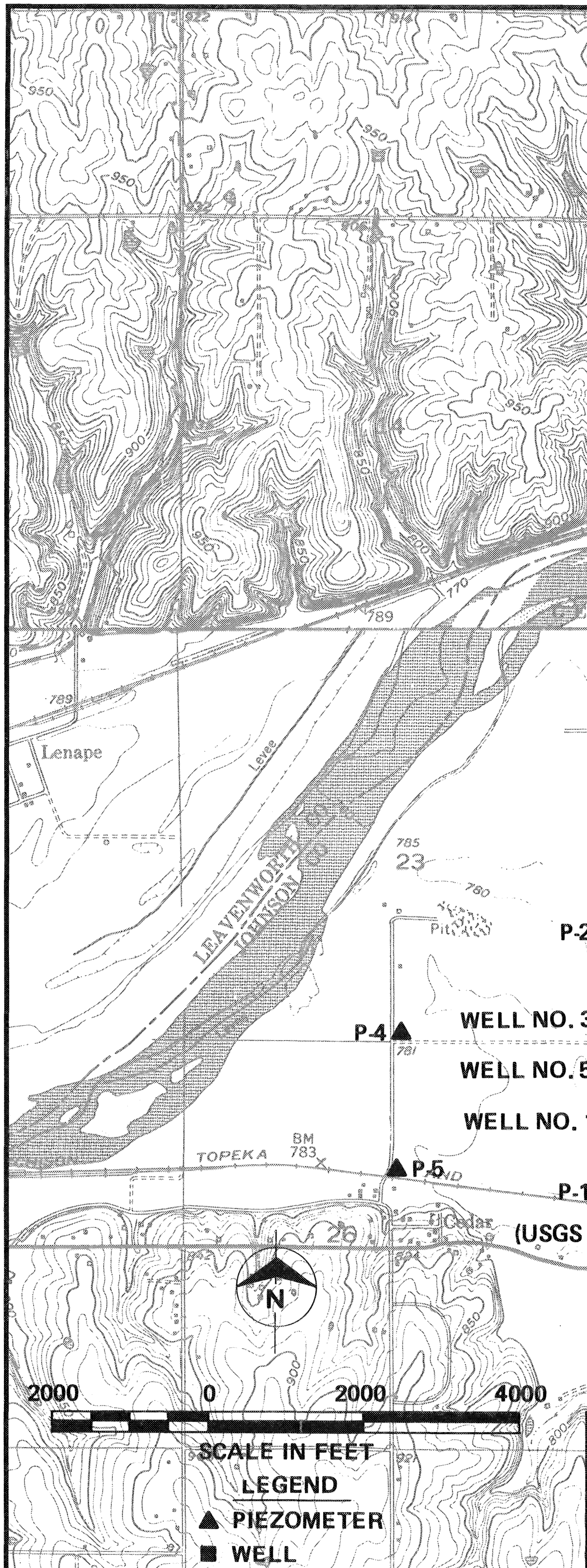

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Figure I-10
WELL AND PIEZOMETER LOCATION MAP
OLATHE, KANSAS

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

sand grading with depth from a medium fine to medium coarse sand with some gravel. A buried valley exists in the bedrock below the well field with elevations near the south valley wall 10 to 25 feet deeper than elevations near the center of the valley. Wells in the deeper alluvial deposits of the valley have greater potential to produce larger quantities of water than wells in the more shallow deposits near the center of the valley.

Typical well construction details are shown in Figure I-11. The first wells were constructed in 1964 and the last wells were constructed in 1981. All wells have 20 feet of screen, except for well Nos.10 and 11 which have 25 feet of screen.

c. Groundwater Pumpage

Groundwater pumpage from the well field for the last 4 years is shown in Table I-4. The current capacity of the well field is approximately 6.5 to 7 MGD.

Table I-4

OLATHE, KANSAS
GROUNDWATER PUMPAGE

Year	Pumpage Per Year (MG)	Pumpage Per Day (MG)	% Change	Annual Power Consumption (kWh)
1982	1,168.4	3.20		2,377,000
1983	1,211.0	3.32	+3.8%	2,435,900
1984	1,480.5	4.06	+22.3%	2,678,500
1985	1,489.3	4.08	+0.5%	2,922,800

WELL DATA

Well	Maximum Rate (gpm)	Elevation Bottom Well (feet USGS)	Elevation Top Screen (feet USGS)
1	500	712.9	732.9
2	500	717.0	737.0
3	300	720.6	740.6
4	300	721.7	742.7
5	500	719.0	739.0
6	700	714.0	739.0
7	500	727.1	750.1
8	500	729.0	749.0
9	500	728.5	748.5
10	500	717.8	742.8
11	500	717.8	742.8

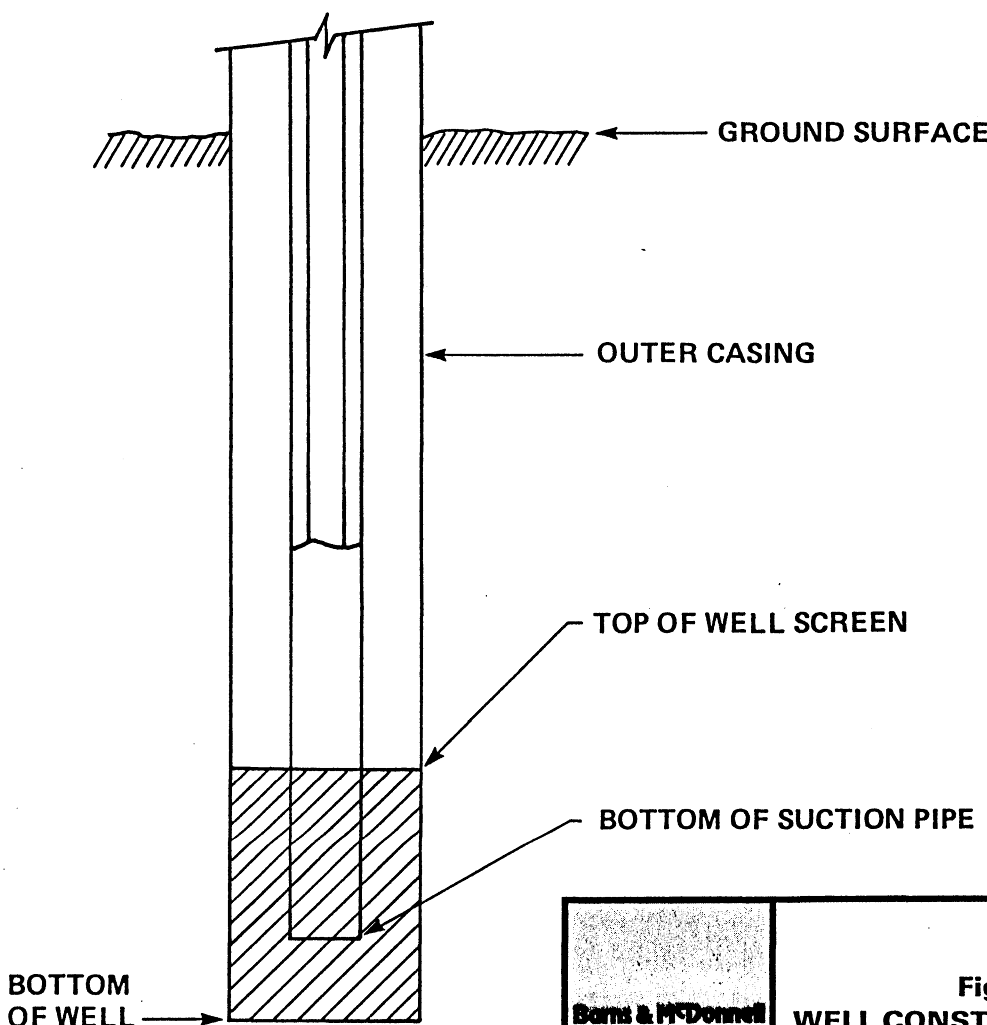

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Figure I-11
WELL CONSTRUCTION DETAILS
OLATHE, KANSAS

Groundwater pumpage accounts for approximately 65 to 70 percent of the raw water treated by the City. The City's other raw water source is new Olathe Lake which is reported to have a safe yield of about 1.0 MGD. The City also obtains treated water from Water District No. 1 of Johnson County, Kansas when needed to supplement existing water sources to meet water demands.

In 1985, the City's average daily water demand was 5.9 MGD. The demand for water is expected to increase about 1 percent per year over the next 5 years. Groundwater pumpage in 1990 is projected to be 4.3 MGD. To meet growing water demands, the City plans to add another well in 2 to 3 years.

d. Operation and Maintenance

The City performs well maintenance by using both its own operation and maintenance staff and contractors. Approximately $15,000 per year is spent on contractors for repairing and rebuilding pumps and another $5,000 per year is spent on miscellaneous materials for well maintenance. City staff labor costs for well operation and maintenance are not available. Records of well operating time for the last four years are shown in Table I-5.

Table I-5
OLATHE, KANSAS
WELL PUMP OPERATING TIME

Well No.	Operating Hours by Year 1982	1983	1984	1985
1	2,247	929	5,402	2,812
2	222	308	1,187	2,130
3	1	96	2,748	3,182
4	47	2,062	5,801	7,172
5	4,457	7,240	7,224	5,893
6	8,599	6,518	5,173	6,739
7	5,304	4,098	5,513	2,692
8	3,713	6,833	3,953	5,269
9	8,646	2,968	1,821	5,187
10	7,632	7,454	6,365	4,458
11	6,321	5,898	8,140	5,501
Total	47,189	44,404	53,327	51,035

Wells in the well field experience reduced pumping capacity (specific capacity) due to mineral incrustation of screens and the gravel pack. The operating water level in some wells occasionally drops below the top of the screens. When this occurs, the City throttles the well discharge valves which raises the operating water levels. Operation with water levels in the screens is avoided whenever possible because increased mineral deposition is believed to occur under this condition.

The City has established a well monitoring and treatment program in an effort to maintain well production capacity. Every six months, the wells are tested for specific capacity and wells with low specific capacities are treated. Approximately 3 to 5 wells are treated each year which results in the treatment of each well every 2 to 3 years.

Recent contractor cost estimates for treating the wells are shown in Table I-6. The difference in treatment costs is due to the difference in the sizes of the wells.

Table I-6

OLATHE, KANSAS
WELL TREATMENT COSTS

Well Nos.	Estimated Treatment Cost
1 through 4	$3,545
5 and 9	$3,895
6, 7. 8, 10 and 11	$4,655

Specific capacity records for each well are shown in Table I-7. Changes in specific capacity with time and recovery of specific capacity with treatment are shown in Figures I-12 through I-14.

Table I-7

OLATHE, KANSAS
WELL SPECIFIC CAPACITY
(TESTED IN SPRING 1986)

	Specific Capacity		
Well No.	Original	Present	% of Original
1	117	59	50
2	75	69	92
3	91	50	55
4	57	46	81
5	147	97	66
6	177	88	50
7	92	102	111
8	104	78	75
9	92	114	124
10	78	54	69
11	116	135	116
Average Specific Capacity for All Wells:			81%

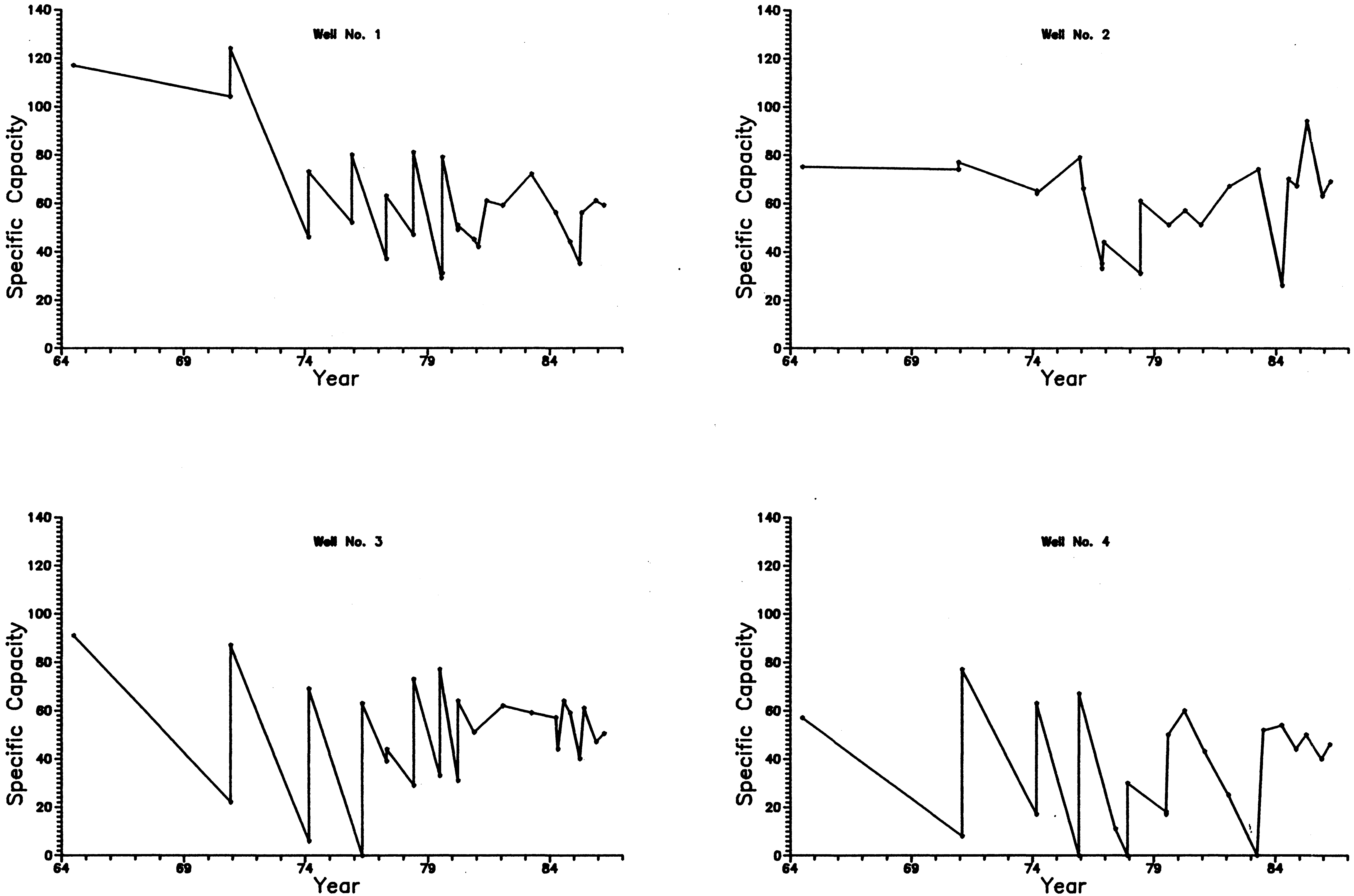

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Figure I-12
WELL SPECIFIC CAPACITY DATA
OLATHE, KANSAS

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

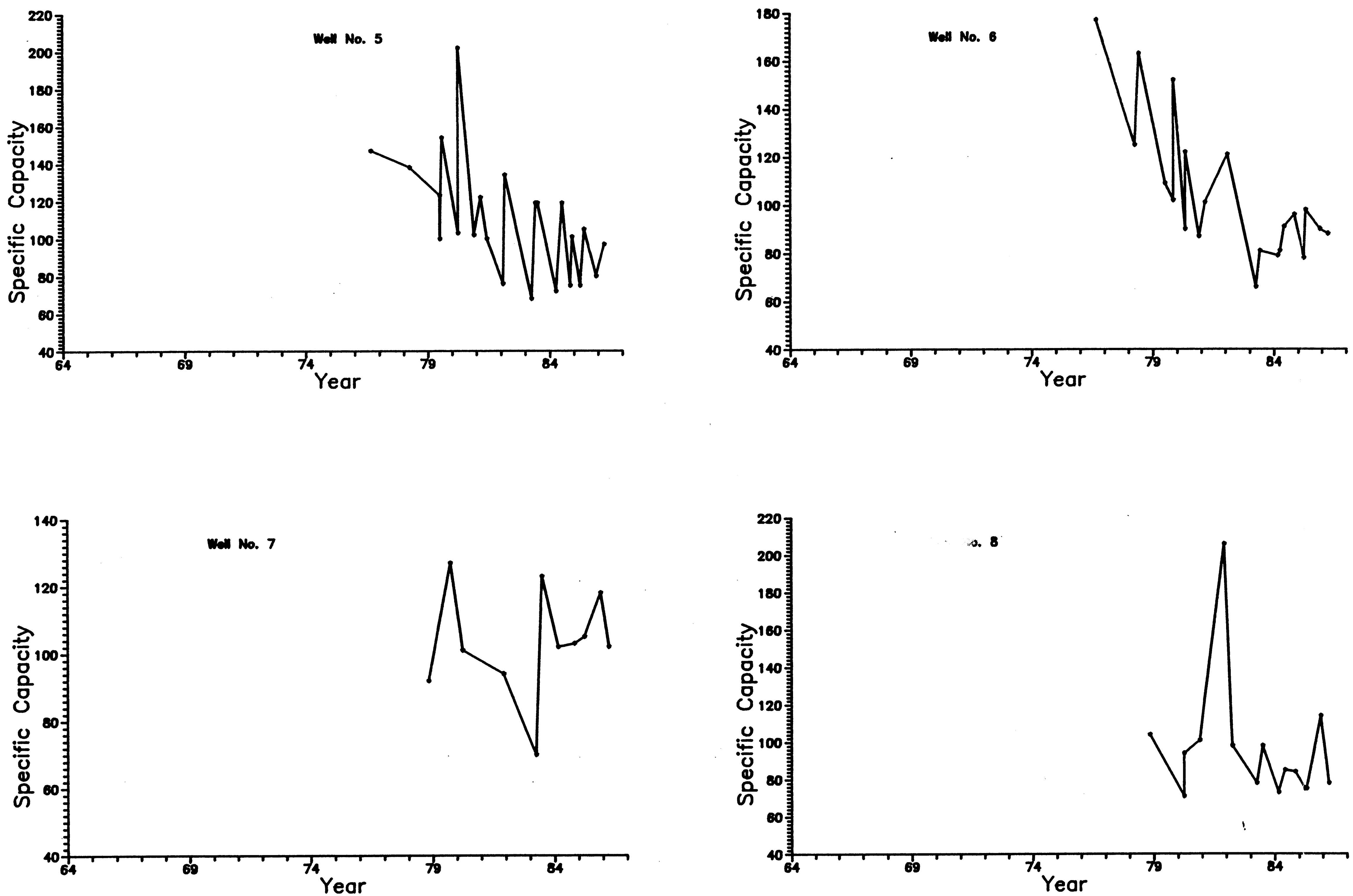

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Figure I-13
WELL SPECIFIC CAPACITY DATA
OLATHE, KANSAS

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

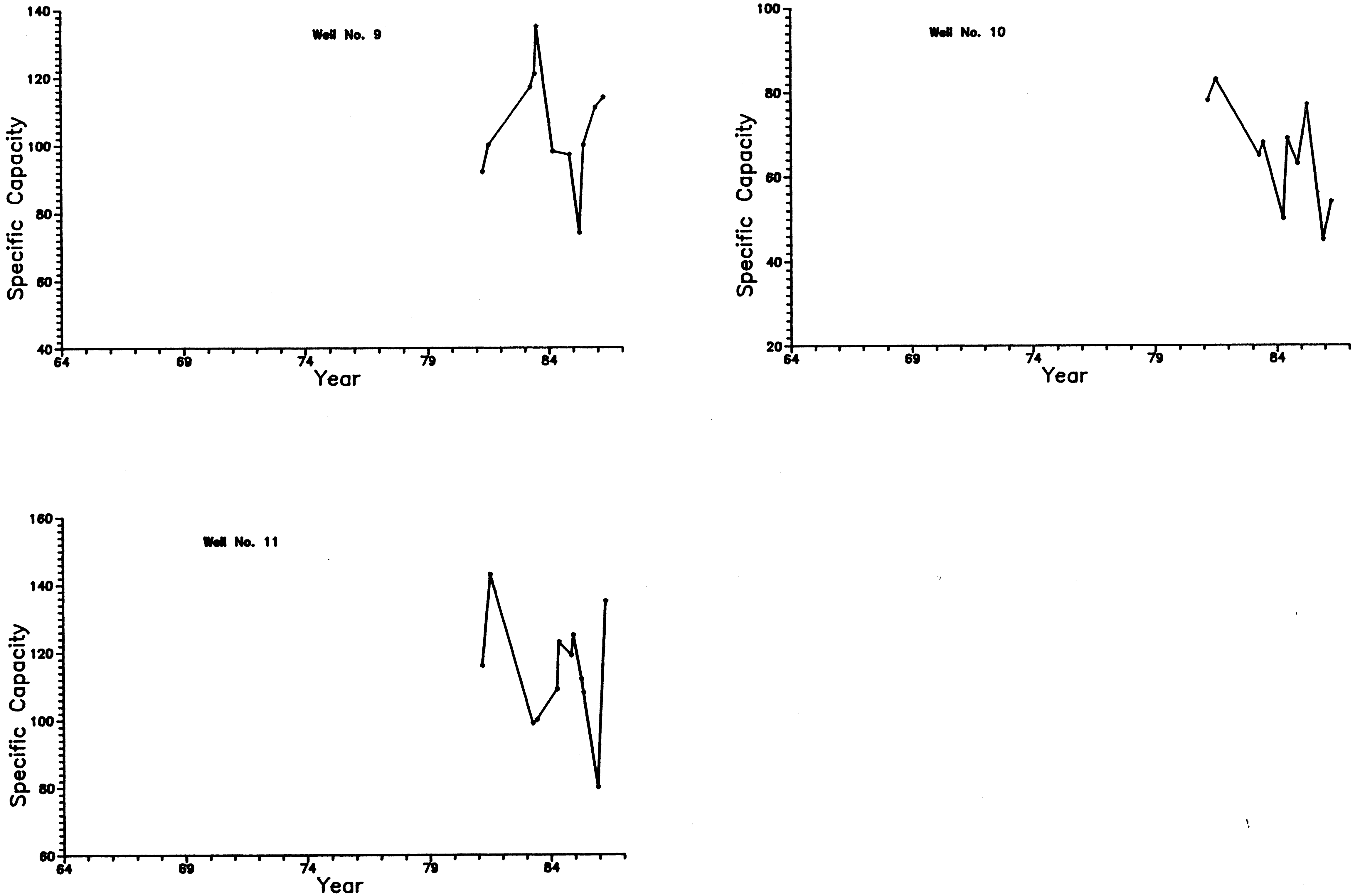

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Figure I-14
WELL SPECIFIC CAPACITY DATA
OLATHE, KANSAS

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

Specific capacities of individual wells after treatment range from 50 percent to 124 percent of original values. The average specific capacities of all wells is 81 percent of original values.

4. DESOTO, KANSAS

a. Overview

The City of DeSoto, Kansas obtains groundwater from the Kansas River alluvium as its sole source of raw water for the municipal water system. The water system serves a city population of approximately 2,100 and provides wholesale water to Rural Water District No. 6 of Johnson County, Kansas.

b. Well System

The City's well field includes 4 wells along the Kansas River near R.M. 32 as shown in Figure I-15. Average daily production from the well field is approximately 0.4 MGD.

Wells in the well field have depths ranging from 45 to 62 feet. Upper alluvial materials consist of silty clay, silt and fine sand to a depth of 12 to 25 feet and underlying material consists of medium sand, coarse sand and gravel with cobbles and occasional boulders above the shale and limestone bedrock.

Well construction details are shown in Figure I-16. Well Nos. 3, 4 and 5 have submersible pumps and Well No. 6 has a vertical turbine pump. The City expects to construct 2 new wells in the

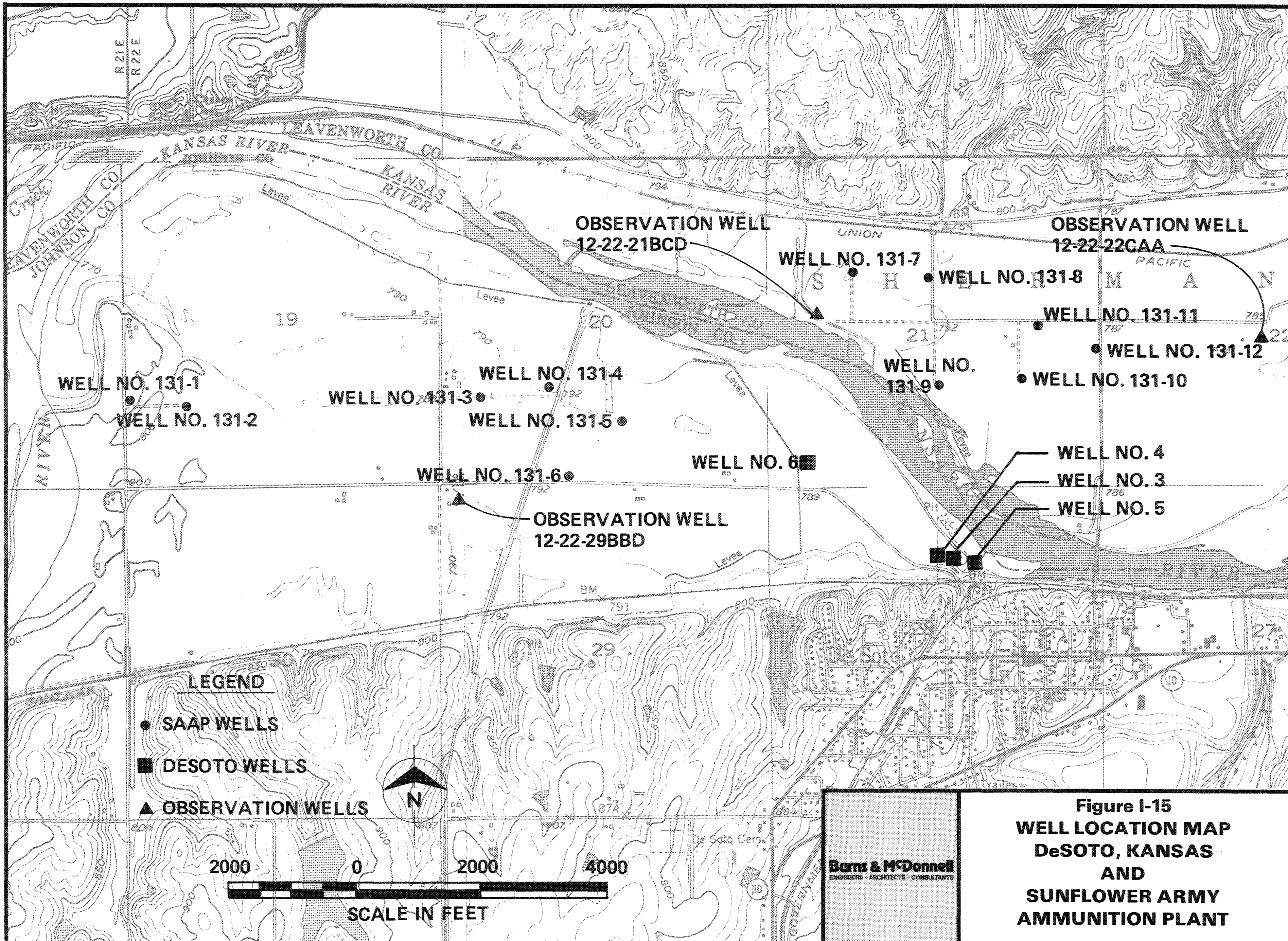

Figure I-15
WELL LOCATION MAP
DeSOTO, KANSAS
AND
SUNFLOWER ARMY
AMMUNITION PLANT

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

Well #	Depth (Feet)	Elevation Bottom Well (Feet USGS)	Screen Length (Feet)	Rate (gpm)	Specific Capacity	Comment
3	62.75	727.25	10	298	—	Relined 1982
4	66.3	723.67	10-15	304	—	—
5	45.5	744.5	—	356	—	—
6	46.0	743.10	15	300	46.7 gpm/ft of draw down	Drilled 1981

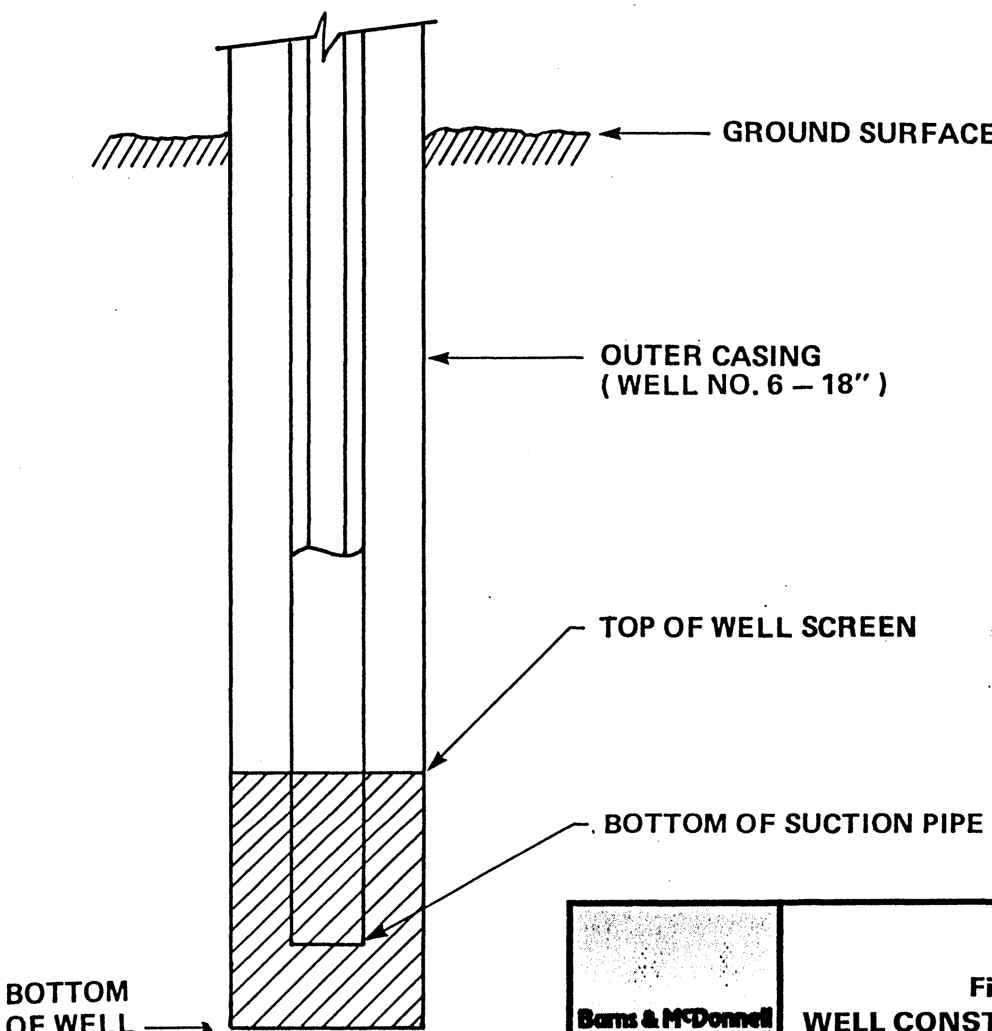

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Figure I-16
WELL CONSTRUCTION DETAILS
DeSOTO, KANSAS

WELL DATA

Well Number	Land Surface Elevation (Feet USGS)	Well Data Screen Top Elevation (Feet USGS)	Elevation of Bottom of Well (Feet)	Static Water Elevation (Feet USGS)	Elevation of Bottom Suction Pipe (Feet USGS)
1	801.94	757.94	742.94	778.44	748.07
2	801.97	759.89	744.89	781.29	747.92
3	785.52	755.42	740.42	774.22	742.22
4	783.59	750.59	735.59	771.01	738.72
5	784.14	759.30	744.30	776.14	746.30
6	785.78	749.41	734.41	774.78	741.13
7	785.49	744.47	729.49	767.49	741.13
8	784.28	748.28	733.28	767.28	741.13
9	781.38	734.88	719.88	768.38	741.13
10	782.22	737.22	722.22	771.22	741.13
11	786.37	743.87	728.87	769.37	741.13
12	783.14	742.81	727.81	771.14	741.13
13	790.3	755.4	735.40	777.00	740.13

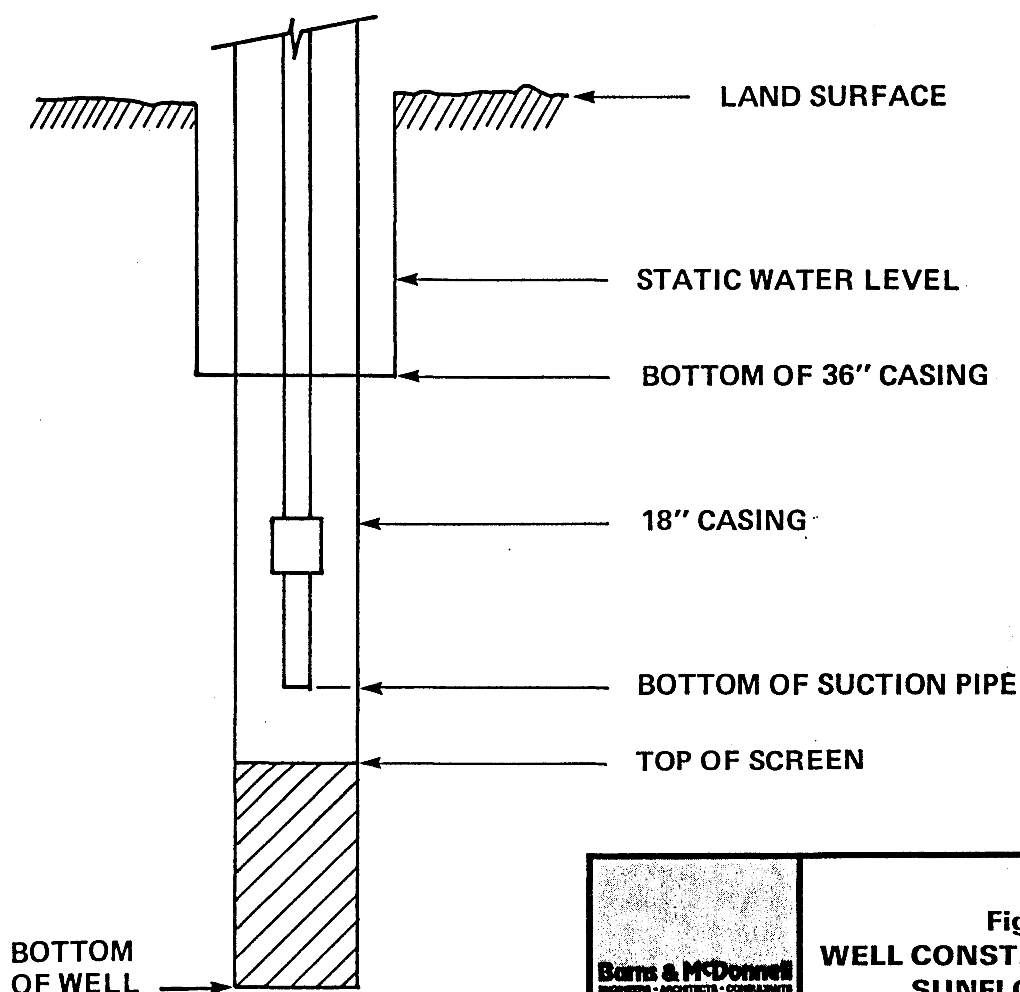

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Figure I-17
WELL CONSTRUCTION DETAILS
SUNFLOWER ARMY
AMMUNITION PLANT

next 2 to 3 years. Each well will have a capacity of 150 to 200 gpm. These wells will probably be located west of the existing well field.

c. Groundwater Pumpage

Groundwater pumpage from the well field for the last 5 years is shown in Table I-8.

Table I-8
DESOTO, KANSAS
GROUNDWATER PUMPAGE

	Per Year (MG)					
	Well No.					Per Day
Year	3	4	5	6	Total	(MG)
1981	54.5	58.1	11.3	19.0	142.9	0.39
1982	35.8	30.6	9.7	49.0	125.1	0.34
1983	36.2	46.2	14.3	61.7	158.4	0.43
1984	43.0	40.2	12.8	44.9	140.9	0.39
1985	30.0	40.0	16.2	37.0	123.2	0.34

In the future, population growth in the City is expected to create increased demand for water. One proposed development project which is currently under consideration is a new subdivision for 500 homes.

d. Operation and Maintenance

Well Nos.3, 4 and 5 are treated every 2 to 3 years and Well No.6 is treated every year to remove mineral incrustations in an effort to maintain production capacity. Specific capacity records for each well are shown in Table I-9. The City recently replaced the pump in Well No. 6 because the original pump was over sized.

Table I-9

DESOTO, KANSAS
WELL SPECIFIC CAPACITY

Well No.	Original	Before Last Treatment	After Last Treatment	% of Original
3	Unknown	<17	41	---
4	Unknown	9	42	---
5	13	2	26*	200
6	47	10	55	117

* Some fine sand is pumped from well.

5. SUNFLOWER ARMY AMMUNITION PLANT

a. Overview

The Sunflower Army Ammunition Plant (AAP) near DeSoto, Kansas is used for the production of ordnance for the U.S. Government. The plant began operations in the 1940's as the result of World War II and is now operating at partial capacity. If a national emergency should occur, all plant production facilities may be returned to service.

The plant may use two sources of raw water in the production of ordnance, including surface water from the Kansas River and groundwater from the Kansas River alluvium. The surface water facilities are currently deactivated to standby condition and only the groundwater facilities are presently being used for water supply.

Certain manufacturing processes at the plant require the use of groundwater which has lower salinity than the surface water. Groundwater from the well fields receives aeration in a cascade aerator for the removal of carbon dioxide and iron and is treated in a water softening plant for hardness reduction and demineralization.

b. Well System

The Sunflower AAP groundwater system includes 12 wells in two well fields along the Kansas River as shown in Figure I-15. The north well field contains 6 wells north of the Kansas River at R.M. 31 and the south well field contains 6 wells south of the Kansas River at R.M. 34. The well system had an original design capacity of 10 MGD. In 1985, groundwater production averaged approximately 2 MGD.

Wells in the well fields have depths ranging from 40 to 60 feet. The upper 12 to 25 feet of soil consists of silty clay, silt and fine sand and the underlying material consists of medium and coarse sand and gravel with some cobbles and boulders above bedrock. A buried bedrock channel lies near the north valley wall and thicker saturated layers in this area yield greater volumes of water to wells than the thinner materials on the south side of the river.

Typical well construction details are shown in Figure I-17. All wells were installed in 1942 of similar construction. Outer steel well casings are 38-inches in diameter and extend from 15 feet below ground up to the pump base. Inner steel well casings are 18-inches in diameter and have attached 18-inch diameter, 15 feet long well screens near bedrock. The annular space between the two casings is filled with gravel pack material.

c. Groundwater Pumpage

Groundwater pumpage from the well fields for the last 11 years is shown in Table I-10. The two well fields produced approximately 10 MGD from start-up in 1942 until the end of World War II. After the war, the ordnance plant operated at lower production rates or was in standby condition which required less groundwater. As the data shows in Table I-10, the north well field has historically always out-produced the south well field.

Table I-10

SUNFLOWER AAP
GROUNDWATER PUMPAGE

	Per Year (MG)			Peak
	Well Field			Month
Year	South	North	Total	(MG)
1975	62	187	249	25
1976	33	201	234	30
1977	48	178	226	32
1978	43	226	269	28
1979	64	273	337	50
1980	52	473	525	65
1981	40	459	499	
1982			355	
1983			361	
1984			585	
1985			742	

d. Operation and Maintenance

Wells in the two well fields were first treated to help maintain production capacity during World War II. As well field

Table I-12

INDUSTRIAL RIGHTS FOR GROUNDWATER USE
(LOWER KANSAS RIVER VALLEY)

Right Number	Date	Company	Well Location	Authorized Flow Rate (gpm)	Authorized Flow Amount (AFY)	Comments
WY0011-V	Vested	Lone Star Industries	SW NE SW 28 11 23 01	600	613.8 (combined)	2 wells; reported rates of 280 & 250 gpm in last several years.
5144	02-16-56		SW NE SW 28 11 23 02			
33076	05-07-79					
35592	08-14-81	Superior Sand & Gravel	2550 N 1100 W 31-11-24	650	369.5	No reports of use from 1981-1985.
35593	08-14-81		3150 N 400W 31-11-24	250	11.5	600 gpm reported in 1981; no reports of use from 1982-1985.
36216	08-18-82	Builders Sand	700 N 250W 28-11-23	100	32.22	750 gpm reported in 1983; no reports of use in 1984-1985.
37092	03-06-84	Griffin Wheel Co.	2827 N 5300W 22-11-24	20	5.04	10 gpm reported in 1984; 891 gpm reported in 1985.

Table I-13

IRRIGATION RIGHTS FOR GROUNDWATER USE
(LOWER KANSAS RIVER VALLEY)

Right Number	Date	Name	Well Location	Authorized Flow Rate (gpm)	Authorized Flow Amount (AFY)	Comments
1762	08-28-53	Curth, Charles	CS SE SW 28-11-24	400	73.5	No reports of use.
6594	12-29-56	Caldwell, Wm.	SE NW SE 23-12-22	330	30	No reports of use.
6849	02-04-57	Wendt, Otto	SW SE NW 33-4-23	360	19	No reported use from 1982-1985.
9730		Hodgon, Brewster	NE SW NW 26-12-22	355	14	Reported 300 and 575 gpm; not used in recent years.
10125	06-16-64	Darby, Harry	NC NE NW 18-12-23	420	29.3	Reported no use from 1981-1985.
28898	02-14-77	Riverside Farms	NC NE 26-12-21	1000	153	650 gpm reported 1977-78; no reports of use from 1977-1985.
28899	02-14-77	Riverside Farms	SW SW NE 19-12-22 NE NE SE 19-12-22	2300 (combined)	293 (combined)	Reported 800 gpm, 35.35 AF in 1979; no reports of use from 1980-1985.

and seven applications from six individuals for irrigation water rights.

b. Well System

Six industrial and eight irrigation wells are shown along the Kansas River in Figure I-18. Construction details of wells are generally unknown or missing. Many well owners do not remember who drilled the well.

c. Groundwater Pumpage

Authorized groundwater withdrawal rates for industrial water range from 20 to 650 gpm and total annual authorized usage ranges from 11.5 acre-feet per year (AFY) for a single well application to 613.8 AFY for a combined application with two wells. Most industrial rights are larger and have more continuous use than the irrigation rights.

Authorized groundwater withdrawal rates for irrigation water range from 330 gpm for a single well application to 2300 gpm for a combined application with two wells and total annual authorized usage ranges from 15 to 293 AFY. In order to keep from exceeding the annual authorized usage, only 10 to 42 days of continuous well pumping is possible at the pumping rates indicated. Most well owners report no use in recent years.

d. Operation and Maintenance

Operation and maintenance of these wells is believed to occur on an "as needed" basis.

E. CONCLUSIONS

The geology of the lower Kansas River Valley is largely influenced by glacial activity with the valley generally marking the southern limits of the glacial advance. The floodplain alluvium was formed by material erosion and deposition and generally includes upper layers of fine silts and clays, intermediate layers of fine sands and lower layers of coarse sands and gravels. The floodplain is underlain by Pennsylvanian age bedrock with predominant limestone and shale seams.

Degradation of the Kansas River channel (and the associated lowering of river water levels) is occurring in the lower reach of the Kansas River from DeSoto, Kansas (R.M. 24) to the Turner Bridge (R.M. 10). Groundwater hydrologists have long recognized the interrelationship between groundwater levels in the Kansas River alluvium and river stages. Declining river stages are expected to affect, to some extent, pumping operations in most well fields along the Kansas River.

Groundwater users which will likely be impacted by channel degradation and lower river stages include Water District No. 1 of Johnson County, Kansas; the cities of Bonner Springs, Olathe, and DeSoto, Kansas; the Sunflower Army Ammunition plant, and miscellaneous industrial and irrigation wells along the river. Wells operated by these entities typically require periodic chemical treatment with acids and phosphates to maintain production capacity by removing mineral incrustations which accumulate in the well screens and aquifer formations over time during pumping operations. The formation of these incrustations is believed to be hastened by aquifer over-pumping and by drawdown of the water table into the well screens. Pumping capacity is currently limited in most well fields to an allowable drawdown available within the saturated thickness of each aquifer formation.

* * * * *

PART II—DATA COLLECTION AND ANALYSIS

PART II

DATA COLLECTION AND ANALYSIS

A. GENERAL

This report section discusses data collection and analysis procedures used to evaluate groundwater system impacts caused by declining river stages in the Kansas River as the result of channel degradation of 1, 3 and 5 feet. The collected data is used to establish groundwater computer models in three groundwater systems as discussed in Part I of this report (refer to Figure I-1).

B. DATA COLLECTION

In order to evaluate the impacts of lower river levels caused by channel degradation, historical data is used to show the interaction of the river and groundwater systems and to establish baseline conditions and trends in groundwater levels. This information is used to establish parameters for the groundwater models and to calibrate the groundwater models.

Information provided by the Corps of Engineers for this study includes well and well field information from Water District No. 1 of Johnson County, Kansas, the Cities of Olathe and DeSoto, Kansas and the Sunflower Army Ammunition Plant. This information includes miscellaneous reports, well tests, maps, well construction details, water level readings and partial operating data. Other data provided by the Corps of Engineers includes river surface profiles, river cross sections, river stage and discharge information, and previous reports and studies of the Kansas River.

These studies include:

- Bank Erosion Inventory, January 1978, Corps of Engineers.
- Channel Migration Study, July 1979, Corps of Engineers.
- Hydrologic Investigation and Preliminary Engineering Report: Wellfield Improvement Program, Sunflower Army Ammunition Plant, DeSoto, Kansas, 1982, DeWild Grant Reckert & Associates.
- Report on the Cumulative Impacts of Commercial Dredging on the Fishery of the Lower Kansas River, 1982, University of Kansas.
- Report on the Cumulative Impacts of Commercial Dredging on the Kansas River: A Social, Economic and Environmental Assessment, 1982, Burns & McDonnell Engineering Company.
- Analysis of Channel Degradation and Bank Erosion in the Lower Kansas River, 1984, Simons, Li and Associates.
- Recommendations for a Plan to Regulate Commercial Dredging on the Kansas River, 1985, Simons, Li and Associates.
- Final Design Report and Specifications for Wellfield Improvements, Sunflower Army Ammunition Plant, DeSoto, Kansas, 1985, DeWild Grant Reckert & Associates.
- Kansas River Dredging Operations, Baseline Study and Comparison of Alternatives, 1986, Booker Engineers.

Additional information is available from the Kansas Geological Survey, the U.S. Geological Survey, the Kansas Division of Water Resources and the Layne-Western Company. Information is also available from each groundwater user concerning well construction, well pumping, historical operating conditions and operation and maintenance procedures and costs.

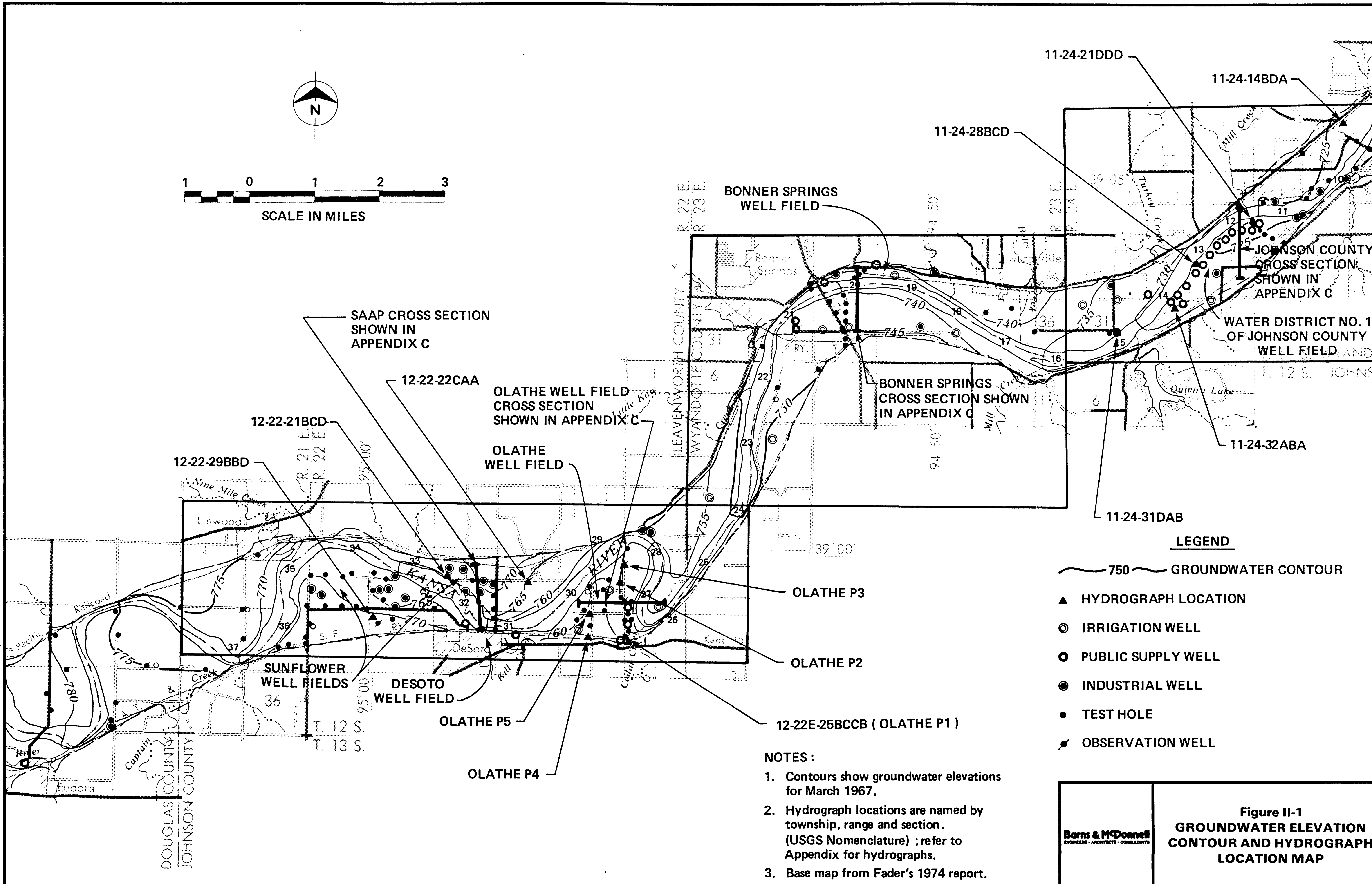
Much of the early information concerning groundwater in the lower Kansas River is summarized in a 1974 document titled Kansas Geological Survey, Bulletin 206, Part 2, Groundwater in the Kansas River Valley, Junction City to Kansas City, Kansas, by Stuart W. Fader. This report and supplemental data collected for the study contains the basic information used to establish the hydrogeologic parameters contained in the groundwater computer models.

C. DATA ANALYSIS

1. GROUNDWATER CONFIGURATION AND TRENDS

In order to establish the current groundwater configuration and to determine trends in the water table, a series of hydrographs are plotted (refer to Appendix A) using long-term observation well data compiled from the United States Geological Survey (USGS) and other sources for observation wells shown in Figure II-1. Although the observation well readings are not continuous and do not show the rate of groundwater response to river stages, the well levels do follow the general river level trends. A linear regression analysis of the available hydrograph data, shown on each of the figures in Appendix A, indicates a general downward trend in groundwater.

Areas of the river valley adjacent to river reaches which experience significant river bed degradation probably also experience similar declining groundwater levels. Only a few observation wells exist



NOTES :

1. Contours show groundwater elevations for March 1967.
2. Hydrograph locations are named by township, range and section. (USGS Nomenclature) ; refer to Appendix for hydrographs.
3. Base map from Fader's 1974 report.

Figure II-1
GROUNDWATER ELEVATION CONTOUR AND HYDROGRAPH LOCATION MAP

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with records extensive enough to show such degradation impacts. The hydrograph of one such well (12-22E-25CCB, Appendix Figure A-6) near the Olathe well field does give evidence of groundwater decline. The hydrograph shows a distinct drop in water level during a period around 1975 and has since remained relatively constant with only minor level fluctuations.

2. COMPUTER MODEL DESCRIPTION

In this study, a mathematical groundwater computer model, the Prickett-Lonnquist Aquifer Simulation Model (PLASM), is used to relate the hydrological interaction of well fields, alluvial aquifers and the Kansas River. The model simulates aquifer responses under a number of operating scenarios and is used to analyze the complex inter-relationship of river stages and groundwater levels under well field pumping conditions. The model is "calibrated" to establish various hydrogeologic parameters by matching historical groundwater levels from various data sources. The calibrated model is, in turn, used to determine the changes in the groundwater levels of various well fields resulting from 1, 3 and 5 feet of river channel degradation (and associated river stage declines).

PLASM is a two-dimensional, finite difference model that calculates water levels at many locations within the model area as a function of time. PLASM allows for nonhomogenous aquifer conditions with a wide range of recharge and barrier boundaries. The finite difference approach involves replacing the continuous aquifer by equivalent discreet elements that represent specific two-dimensional areas. The mathematical background and basic model foundation is presented in the Illinois State Water Survey Bulletin 55, Selected Digital Computer Techniques for Groundwater Resource Evaluation, 1971.

3. MODEL CONSTRUCTION

The Lower Kansas River Valley is divided into three separate groundwater model areas because of the basin's long, narrow configuration (refer to Figure I-1). Well fields of major groundwater users which are associated with each model include:

- Model Area 1 - Wellfield used by Water District No. 1 of Johnson County, Kansas.
- Model Area 2 - Wellfield used by the City of Bonner Springs.
- Model Area 3 - Wellfields used by the Cities of Olathe and DeSoto and the Sunflower Army Ammunition Plant.

In the main zones of interest, the discreet elements in the models represent 10 acre areas (660 ft. x 660 ft.). Some of the elements bordering primary areas of interest are 1320 ft. x 1320 ft. or 660 ft. x 1320 ft. in size for ease of filing data.

Water levels in each element or node are related to adjacent nodes by mathematical relationships of aquifer parameters including permeability, storage coefficient, aquifer thickness, existing water levels, and recharge/discharge to the aquifer from infiltration, wells, and river leakage. Parameter values are selected for each node or element in the model so that calculated water levels match measured field data.

Initial estimates of the aquifer parameters are based on available data such as pumping tests and previously collected regional water studies. The results of the first model trials are compared with historical water table conditions to check the validity of the parameter assumptions. Adjustments are made to the aquifer parameters and additional runs are made until the model results approximate historical conditions.

4. <u>MODEL PARAMETERS</u>

a. <u>Transmissivity</u>

Transmissivity is a measure of aquifer's ability to transmit water and is defined as the rate of water movement through a unit width of saturated aquifer under a unit hydraulic gradient. Transmissivity (T) is equivalent to the hydraulic conductivity (P) times the saturated thickness (ST) of the aquifer or T = P x ST.

The saturated thickness of an unconfined alluvial aquifer is the difference between the groundwater elevation head and bedrock elevation and is not constant, but varies with time due to changes in river stage. The groundwater model is programed to calculate new transmissivity values at each node to match changing conditions.

b. Hydraulic Conductivity

Hydraulic conductivity of an aquifer is defined as the amount of water that can be transmitted through a unit area (gallon per day per square foot-gpd/ft^2) of an aquifer. Hydraulic conductivity can be determined by well pumping tests or lab permeability tests. In-situ pumping tests are preferred because of the accuracy of information obtained under field conditions.

Aquifer characteristics from 12 aquifer pumping tests in Douglas, Johnson and Wyandotte Counties in Kansas are shown in Table II-1. This information is used in model runs in appropriate areas and trial parameters are used in areas where data is not available. Values are adjusted in calibration runs until historical conditions are matched. Once hydraulic conductivity values are established for each node (refer to Appendix figures B-1 to B-3), no changes are made in the model runs of various degradation scenarios.

c. Initial Water Levels (Head)

Because of the river water-groundwater interaction, groundwater levels eventually reach equilibrium conditions over an extended period of constant river flow. Calibration runs of the initial model are simulated for a 20-year period to obtain steady-state conditions to adjust calculated groundwater elevations to match river stages.

Table II-1

AQUIFER PUMP TEST INFORMATION IN KANSAS RIVER VALLEY-FILL DEPOSITS

Douglas County, Kansas

Well	Transmissibility (gpd/ft)	Saturated Thickness (feet)	Permeability (gpd/ft^2)	Location
12-20E-29aca	40,000	26	1540	Near Lawrence
12-20E-35ccc3	147,000	49	3000	Coop - East of Lawrence
13-20E-2bcb	130,000	19	6840	Coop - East of Lawrence

Johnson County, Kansas

Well	Transmissibility (gpd/ft)	Saturated Thickness (feet)	Permeability (gpd/ft^2)	Location
12-22E-24ccc2	140,000	32	4375	Olathe well field
12-22E-25bbc	180,000	44	4090	Olathe well field
12-22E-28a	83,600	21.5	3890	DeSoto Test Well
12-22E-28a	58,200	—	—	DeSoto Well 6
12-22E-25ccc	94,200	22	3770	Olathe aquifer test

Wyandotte County, Kansas

Well	Transmissibility (gpd/ft)	Saturated Thickness (feet)	Permeability (gpd/ft^2)	Location
11-24E-21ddd	165,000	34	4850	W.D. No. 1 of Jo. Co.
11-24E-29cdc	139,000	34	4090	W.D. No. 1 of Jo. Co.
11-24E-31dab	136,000	32	4250	W.D. No. 1 of Jo. Co.
11-24E-32aba	239,000	41	5830	W.D. No. 1 of Jo. Co.

The 20-year total time period is divided into 6 time steps which allows transmissivities to be adjusted for changes in saturated thickness. The groundwater levels determined for the average river flow for the three cases (1, 3 and 5 feet degradation) are used as initial conditions for the low flow simulations.

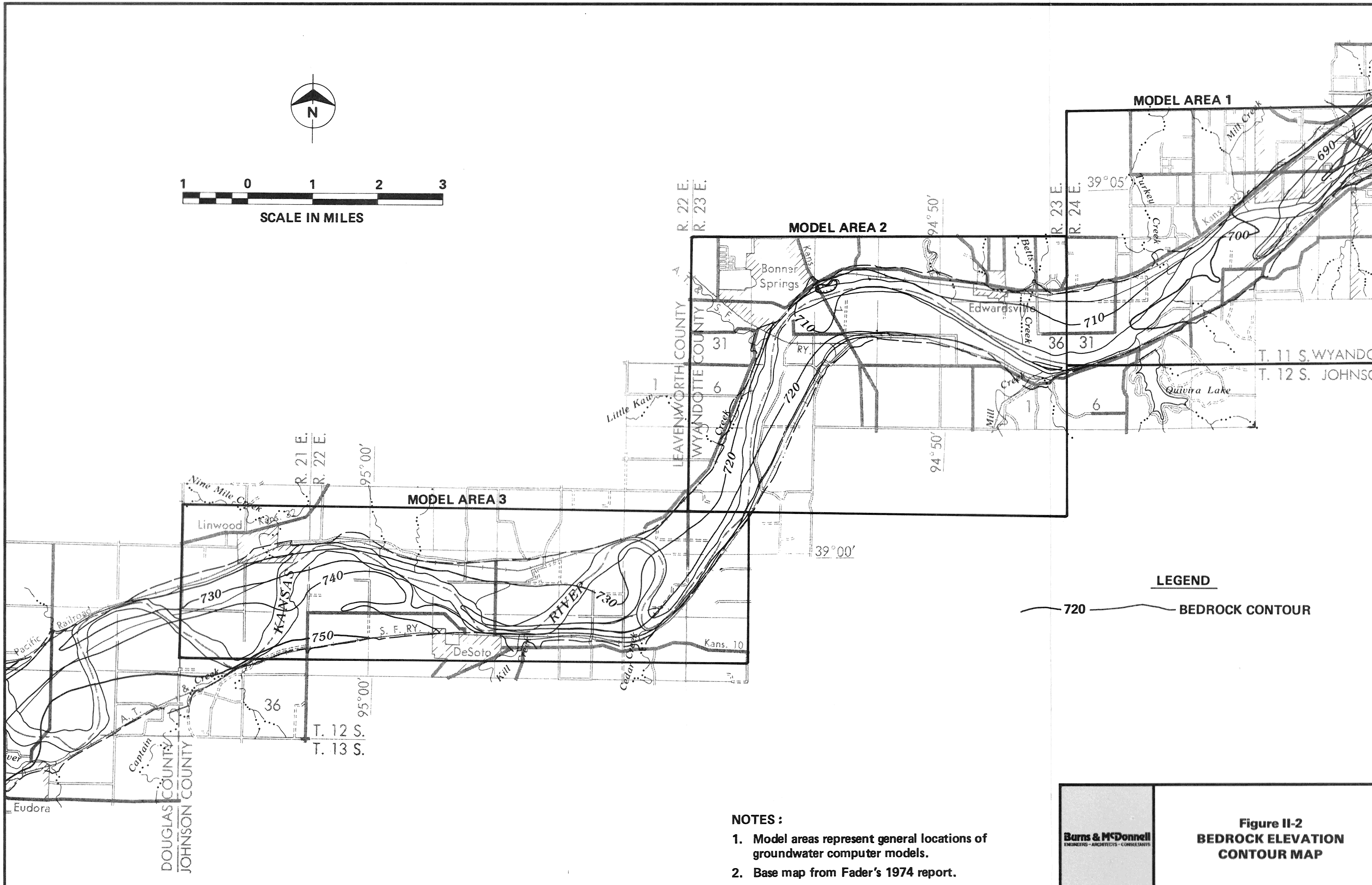
d. Bedrock Elevation

Bedrock is the effective lower boundary of the alluvial aquifer and is composed of seams of limestone, shale and, in some places, sandstone. The bedrock valley floor was formed by glacial outwash erosion and deposition and its configuration is described in Fader's 1974 work.

Bedrock contours used in the three groundwater model areas are shown in Figure II-2. The bedrock configuration is incorporated in the groundwater models as the lower boundary with only minor changes based on recent collected data.

e. Storage Coefficient

Storage coefficients of alluvial aquifers are sometimes difficult to determine from short term pumping tests because of delayed drainage. As water levels are drawn down, parts of the aquifer above the water table are not immediately drained. The effects of surface tension on individual aquifer particles slows the complete dewatering of the material. According to Fader's work, if pumping tests are run for several days, the storage coefficients will range from 0.05 to 0.20 and will average 0.15.



NOTES:

1. Model areas represent general locations of groundwater computer models.
2. Base map from Fader's 1974 report.

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Figure II-2
BEDROCK ELEVATION CONTOUR MAP

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The value of the storage coefficient is not important for "steady-state" conditions because there is no change in storage. The value is important, however, in determining groundwater level changes which occur during "nonsteady state" conditions such as changing from average to low flow river conditions. A value of 0.15 is used in the model case study simulations.

f. Recharge-Discharge Conditions

Several recharge-discharge conditions are important in the model case study simulations. These include groundwater recharge due to infiltration of precipitation through the top soil, seepage (recharge) flow from valley walls, and recharge from irrigation return flow. Groundwater levels are also effected by the river through the river surface elevation, the river bed elevation and the amount of leakage upward or downward through the river bed. Well pumpage also has a major impact on groundwater levels.

(1) Groundwater Recharge-Discharge: Groundwater normally flows from the valley fill to the river because of groundwater recharge by direct infiltration of precipitation on the valley, by seepage from streams and ponds, by return flow from irrigation and by seepage from valley walls. The recharge over a long period of time is assumed to equal the discharge to the river when the system is in equilibrium.

Fader studied the long term water balance and found that the valley fill contributes approximately 2.2 cubic feet of water per second (cfs) per river mile. This was found to vary from 1 cfs per mile during periods of below normal precipitation to approximately 4.3 cfs per mile during wet periods. For an average valley width of 9000 feet, the low flow contribution is approximately 0.015 gallons-per-day per-square-foot (gpd/ft^2) of valley floor. This value is used in most areas of the three models as the critical low flow condition for model operation.

The distribution of the recharge factors for the three model areas is shown in Appendix Figures B-4 through B-6. In several locations, additional recharge is entered into the model to simulate known groundwater levels. An area north of DeSoto appears to have additional recharge, either from the valley walls or from irrigation recharge. This extra recharge creates higher groundwater levels as shown by the high groundwater contours in Figure II-1.

(2) River Conditions for Recharge-Discharge: Parameters for river conditions which influence groundwater flow are also included in the model. These parameters include the river surface elevation, the river bottom elevation, and the permeability or leakance of the river bottom. These values and the groundwater levels determine whether the river receives groundwater discharge (normal condition) or provides river water to the groundwater system.

(a) River Surface Elevation: The river surface elevation is a critical input to the groundwater analysis. This input determines the amount of groundwater discharged into the river or the amount of river water discharged into the groundwater table. The river surface elevation at each node is adjusted in various computer runs to match desired river flow conditions.

The groundwater contours from the Fader Report represent the groundwater configuration in March, 1967, and are used to calibrate the models. During March, 1967, the average river discharge was 670 cfs which is assumed to approximate 1000 cfs for analyses performed in this study. By comparison, the average annual flow in the Kansas River is approximately 7,000 cfs. The river bed profile in 1967 is estimated using the Corps of Engineers' profile and cross section data and the estimated river profile for the 1967 low flow is shown in Figure I-3.

Recurrence intervals for a 1,000 cfs flow are shown in Table II-2. As shown in the table, a flow of 1,000 cfs with a duration of 30 to 60 days will occur about once every 3 years. A duration of 30 to 60 days is used in this analysis because low flow for this period of time indicates drought conditions and generally represents a period of concern for groundwater users. This combination of low flow and length of duration has a return period of about 3 years which is frequent enough to be considered in evaluating the capacity of a well field. Consequently, 1,000 cfs is used in the groundwater model as the critical low flow value.

Table II-2

RECURRENCE INTERVAL FOR 1,000 cfs *
KANSAS RIVER AT BONNER SPRINGS

Flow Duration (Days)	Recurrence Interval (Years)
15	2.5
30	2.75
60	3.6
120	4.0

* Information from Technical Report No. 2. Kansas Streamflow Characteristics. Part 2, Low Flow Frequency, June 1960, Kansas Water Resource Board.

After calibration of the models, the river bottom and water level profiles are set to "current conditions". The most complete river profile data was collected in 1973 and 1977 for near average and low flow. This Corps of Engineers data, plus the values of river profile used in the model as initial or "current" conditions, are shown in Figure II-3. Except for backwater at the weir of the Water District No. 1 of Johnson County intake, the current condition profile are uniformly dropped 1, 3 and 5 feet to model groundwater level changes in each of the case studies.

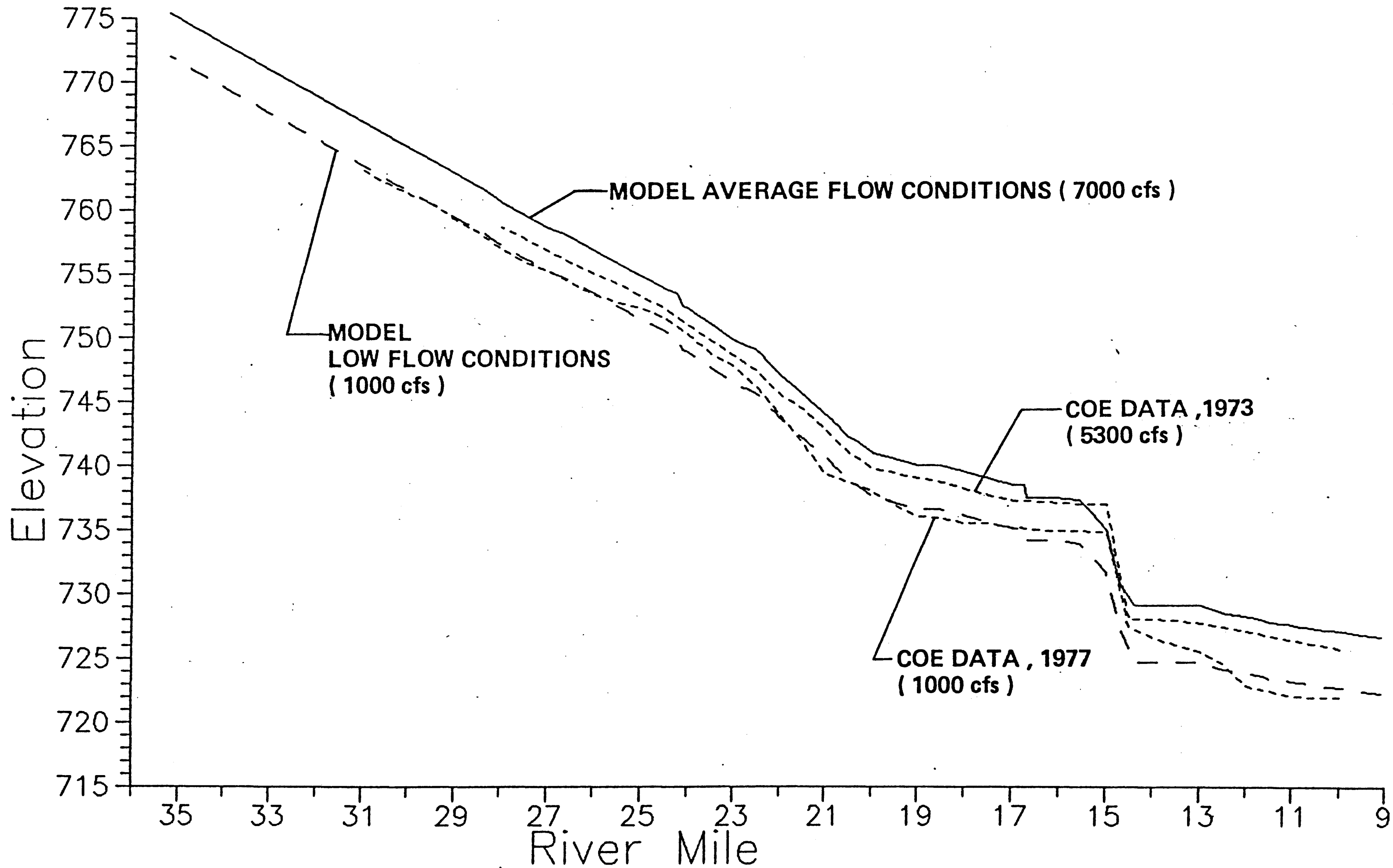

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Figure II-3
WATER SURFACE PROFILE
FOR
MODEL SETUP

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(b) River Bed Permeability: A river's bedload of fine sediments (consisting of fine sand, silt and clay) generally is a barrier to water movement between the river and the aquifer. When the river water surface is above the groundwater level, flow is downward through the river bed to the aquifer. The river, in this case, acts as a water source. When the river surface level drops below the groundwater level, flow is upward through the river bed. The river, in this case, acts as a sink to carry away seepage.

PLASM uses a "Leakance" parameter to consider the effects of the river. Leakance (L) is the permeability (p') of the river bed divided by the thickness of the bed material (m') or L = p'x m'. A value of leakance is determined from information developed during an aquifer test by the City of Olathe in 1980.

A high river bed permeability is indicated by grain size analysis tests of riverbed and river bar materials. Although not directly applicable to bed infiltration, the average D10 grain size, using Hazen's equation, indicates the material is highly permeable. Calculations of permeability using Hazen's equation of river bed and sand bar material give values ranging from 2 to 6,000 gpd/ft^2 and average 2,000 gpd/ft^2.

River bed infiltration rates vary as flow conditions and the size of bedload materials change. An average infiltration rate of 5 gpd/ft^2 is used in the models.

In most cases, the river covers only a part of the node elements in the groundwater models. In order to more accurately represent the area of the node in contact with the river, leakance values are reduced by the ratio of the river area to the total node area for each element area.

(c) River Bed Elevation: River bed elevations are estimated from a series of river cross sections made in 1947 through 1977 by the Corps of Engineers. The 1967 river bottom elevation, the year used for model calibration, is estimated from the Corps' river cross section information. After the groundwater models are calibrated, river bed elevations are set to "current" conditions which are assumed to be represented by the 1977 cross section data. The "current" river bed elevations are lowered 1, 3 and 5 feet in each computer model case study to simulate the three river degradation scenarios.

(3) Well Pumpage: Well pumpage has a significant effect on groundwater levels. As water is removed by wells, the groundwater level in the immediate vicinity of the well is lowered. Well pumpage data in each model are based on annual water use reports from the state and information obtained in interviews with groundwater users.

In the calibration of the groundwater models, pumping rates for existing wells are used to simulate existing conditions. The model for Area 1 includes the Water District No. 1 of Johnson County well field and contains 15 model well points to represent the actual 21 pumping wells with each model well point pumping 0.524 MGD for a total pumping rate of 7.86 MGD. The model for Area 2 includes one model well point for the City of Bonner Springs well field, pumping 0.9 MGD, and two small model irrigation wells, each pumping about 0.1 MGD. After calibration, model input data is altered to reflect changes in well pumping between 1967 and current conditions.

Well pumpage used in the models for 1967 conditions and for current conditions are shown in Table II-3.

Table II-3

MODELED WELL PUMPAGE

Model Area	Well Area	Number of Pumping Well Points		Well Pumpage (MGD)	
		1967	1986	1967	1986
1	W. D. No. 1 of Jo. Co. KS	15	15	7.860	2.900
1	Irrigation Well	0	1	0.000	1.296
2	Bonner Springs, Kansas	1	2	0.900	2.000
2	Industrial Well	1	1	0.144	0.144
2	Irrigation Wells	2	2	0.280	0.280
3	Olathe, Kansas	0	2	0.000	4.078
3	DeSoto, Kansas	0	1	0.000	0.320
3	Sunflower AAP	0	2	0.000	1.876

5. MODEL CALIBRATION

PLASM is operated on an IBM PC-AT with hard disk internal storage. March, 1967 groundwater elevations from the 1974 Fader report are stored in a historical comparison file and are checked against data produced by the model. The historical comparison files are identified as MOD167.DAT, MOD267.DAT, MOD367.DAT, respectively, for Model Areas 1, 2 and 3. Sample computer printouts showing the groundwater elevation data used in the three model areas are contained in Appendix B.

The elevations in each model are reduced to a zero reference plane for ease in modeling operations. Reference elevations for the three model areas are as follows:

Model Area 1: 730 ft. USGS = 0 Datum
Model Area 2: 745 ft. USGS = 0 Datum
Model Area 3: 770 ft. USGS = 0 Datum

The calibration process involves comparing the results of the computer-generated groundwater elevations with historical groundwater elevations observed by Fader in 1967. By adjusting the parameters of aquifer permeability, riverbed leakance and recharge from soil infiltration, the computer models closely match the 1967 reference conditions. The calibrated permeability and recharge distributions are shown in Figures B-1 through B-6 contained in Appendix B. The mean difference between the historical (Fader, 1967) and calibrated groundwater levels is less than 0.2 feet and the standard deviation is less than 1 foot.

6. MODEL GROUNDWATER EFFECTS

a. Methodology

Initial model operations are concerned with obtaining "calibrated", or "equilibrium" situations where data generated by the computer closely match groundwater elevations found in the Fader report. After calibration, models are set to "current" conditions. New groundwater levels are determined by updating calibrated input data to reflect present river surface and river bed elevations based on an average river flow of 7,000 cfs.

"Low" flow conditions, based on the Corps' 1977 river profile for 1,000 cfs, are then established in the models by adjusting the river stages with the following difference between low flow (1,000 cfs) and average flow (7,000 cfs):

Model Area 1:	3.5 feet
Model Area 2:	3.3 feet
Model Area 3:	3.4 feet

All models are run at "average" river levels for a simulated ten-year period to develop average groundwater elevations for comparing the river-lowering effects. Each model data file is modified by subtracting 1, 3 and 5 feet from both the water surface elevation and the river bed. The data is run for another simulated ten-year period to reestablish a steady-state "average" flow condition.

These "degraded" models are further modified to simulate a "low flow" or "drought" situation of up to 180 days by reducing the river surface elevation to "low flow conditions". The "drought" models are run for 30 day intervals up to 180 days. The comparison data for the drought model is obtained by subjecting the original current condition model to the same 180 day drought situation. These values represent the difference in the "low" and "average" stage as determined at the old Bonner Springs gage and the current DeSoto gage.

D. CONCLUSIONS

Historical data on groundwater levels, river stages and river channel elevations are used to show the interaction of the river and groundwater system and to establish baseline conditions for groundwater models. Information on the river and groundwater systems is available from several governmental agencies and groundwater users. The most significant historical data used in this study is the early 1970's groundwater work in the Kansas River Valley by Stuart Fader which was conducted for the Kansas Geological Survey.

A mathematical groundwater computer model, the Prickett-Lonnquist Simulation Model (PLASM), is used to relate the hydrological interaction of well fields, alluvial aquifer and the Kansas River. PLASM is used to model three reaches of the Kansas River Valley including Model Area 1 which encompasses the well field of Water District No. 1 of Johnson County, Kansas, Model Area 2 which encompasses the well field of the city of Bonner Springs, Kansas, and Model Area 3 which encompasses the well fields of the Cities of Olathe and DeSoto, Kansas and the Sunflower Army Ammunition Plant.

The three groundwater models are developed based on available hydrogeologic data and are each calibrated to match Fader's historical groundwater levels in 1967. Once calibrated, each model is operated under current well field pumping conditions to determine groundwater levels resulting from 1, 3 and 5 feet of river channel degradation.

* * * * *

PART III—IMPACT ON GROUNDWATER SYSTEMS

PART III

GROUNDWATER SYSTEM IMPACTS

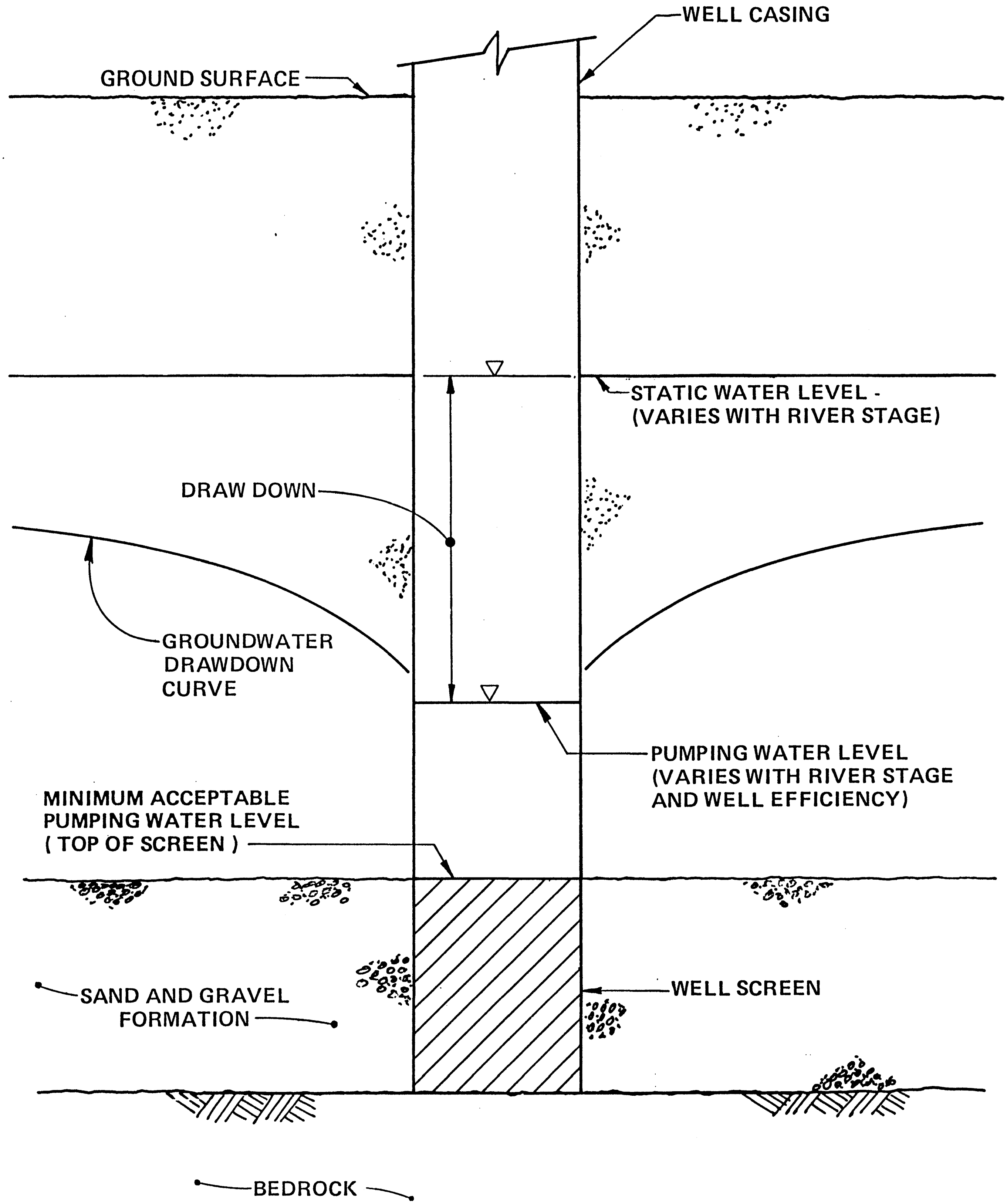
A. GENERAL

This report section discusses the methodology involved in determining impacts to groundwater users as the result of river channel degradation of 1, 3 and 5 feet. Impacts on groundwater levels and operating costs are determined in three groundwater model areas (refer to Figure I-1) for Water District No. 1 of Johnson County, Kansas, the cities of Bonner Springs, Olathe and DeSoto, Kansas, the Sunflower Army Ammunition Plant, and miscellaneous industrial and irrigation well users.

B. METHODOLOGY

The methodology used to determine groundwater system impacts includes the use of computer-derived groundwater levels in each well field (from Part II of this report) and manual computations using site-specific well operating data. Well operating terms used to explain the methodology are shown in Figure III-1.

The computer model projections of groundwater levels for river channel degradation scenarios of 1, 3, and 5 feet previously generated give only general results by model node areas and additional calculations are needed to determine individual well pumping water levels in each well field. The most recently reported specific capacities (well yield expressed in gallons per minute per foot of drawdown) are used to calculate the pumping water level (PWL) for each well using the projected water level as a base or reference level. In this analysis,



NOTE:
Pump column and bowls not shown inside casing for clarity.

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Figure III-1
WELL OPERATING TERMS

the calculated PWL is compared with the minimum acceptable PWL; and, if the calculated PWL is below the minimum acceptable drawdown level (top of well screen), reductions in well yields are determined so that the calculated PWL is equal to the minimum acceptable drawdown level.

Alternative methods, consisting of theoretical calculations and generally accepted well design practice, are used to evaluate the impacts on industrial and irrigation wells because of the unknown construction and operating condition of individual wells. These methods generally include determination of general well construction and computation of the theoretical well yield. Theoretical well yields are computed for each river degradation case and compared with the authorized rate of diversion by the Division of Water Resources.

Impacts to individual groundwater systems include reduced well yields caused by declining groundwater levels and associated increased well field operating costs. River degradation conditions which are investigated for the purpose of determining impacts to groundwater systems include:

- Case 1: One foot of river channel degradation with an accompanying one-foot drop in river water level at low river flow conditions (1000 cfs discharge).
- Case 2: Three feet of river channel degradation with an accompanying three feet drop in river water level at low river flow conditions (1000 cfs discharge).

- o Case 3: Five feet of river channel degradation with an accompanying five feet drop in river water level at low river flow conditions (1000 cfs discharge).

1. MINIMUM ACCEPTABLE PUMPING LEVEL

Most groundwater hydrologists recognize the minimum acceptable pumping levels for good operating practice and prolonged well service to be the top of the well screen. Operation of a well with the water level below the top of screen accelerates mineral incrustation and blockage of the screen and surrounding aquifer formation.

In this study, the minimum acceptable well PWL is defined as the top of the well screen (refer to subsequent well impact tables for elevations). Some wells in the study area are currently operated with water levels in the screen during periods of low river flow. During these conditions, normal operating practice includes throttling the pump discharge to raise the pumping water level above the top of screen. Such operation reduces the detrimental effects of mineral incrustation, but is energy inefficient and results in reduced well production.

2. ESTIMATED PUMPING WATER LEVEL

The projected pumping water level (PWL) for each well is based on computer-generated static groundwater levels during low river flow conditions. In several cases the calculated static groundwater levels are different than the average shown by the regression line in the observation well hydrographs (refer to Appendix A). This may be due to well interference affects on the observation well, additional degradation, or inaccuracy in the river profile or model setup. In observation wells upstream and away from the river, the change is not as great as in wells near the river.

The computer static water levels used in the groundwater computer model are adjusted by amounts determined from the observation well hydrographs. Using the current specific capacity, drawdown is subtracted from the adjusted static water levels to obtain the estimated PWL.

3. INFLUENCE OF SPECIFIC CAPACITY

Specific capacity is a measure of well efficiency and is expressed in terms of gallons per minute per foot of drawdown (gpm/ft-dd). High values of specific capacity indicate efficient wells and good aquifer properties, while low values of specific capacity indicate inefficient wells or poor aquifer characteristics.

Large variations exist between theoretical specific capacities and actual values at individual wells. In cases where actual specific capacity values are greater than theoretical values, localized areas around wells may have better aquifer conditions than the general case that is modeled. Where the specific capacity is less than theoretical, the well may be in an area of poorer aquifer conditions or well construction or maintenance may be limiting aquifer yield.

Specific capacity is largely influenced by well construction techniques. During the development or cleanup phase of well construction, an effort is made to remove fine-grained materials from the water bearing formation. When most fines are removed, water flows freely through the well screen and surrounding aquifer formation which results in a high specific capacity. When fines are not effectively removed, water flow is impeded which results in a low specific capacity.

Specific capacity is also influenced by mineral incrustations which form in the well screens and the surrounding aquifer formations. Most of the wells investigated in this study are highly susceptible to incrustation because of the high mineral content of the groundwater. Such incrustations form when partial gas pressures are reduced as groundwater is induced to flow into the well by pumping operations. As incrustations form, groundwater drawdown increases because of higher head losses through the screen and surrounding formation which, in turn, causes pumping levels to drop. As incrustations form, the mineralization process accelerates because of increasing water velocities and resulting reduction in partial gas pressures.

The mineral incrustation process is exacerbated when the pumping water level drops below the top of screen (referred to as aerating the screen). When this happens, wells may lose over 50 percent of their specific capacity in several years. In some cases (as with Water District No. 1 of Johnson County, Well No. 9), well capacity is reduced to a level at which the well is no longer usable.

Many groundwater users follow well treatment programs as part of their well field operation and maintenance plans. Treatment includes acidization to remove the mineral incrustations and phosphate applications to break down clay particles. After chemical additions, the treated well is redeveloped by surging and pumping to remove fine grain material, sediment or other material left from the treatment process. In a few cases, the additional development may increase a well's specific capacity above that originally attained. In most cases, treatment will improve specific capacity, but will not totally recondition the well and surrounding aquifer to recover original specific capacity.

Lower pumping water levels due to reduced specific capacities can have as much impact as lower river or groundwater levels. A 50 percent reduction in specific capacity, common in the area, will double the drawdown of a well if the pumping rate is maintained at a constant level. For example, a 500 gpm well with a specific capacity of 100 gpm per foot of drawdown (gpm/ft-dd) will have a drawdown of 5 feet, while a 50 percent reduction in specific capacity to 50 gpm/ft-dd will cause a drawdown of 10 feet in order to maintain a 500 gpm output.

Drawdowns are calculated using the latest reported specific capacities and tables of impacts are developed for current specific capacities and for 50 percent reduction in specific capacities. While an individual well may experience 50 percent reduction in specific capacity, an entire well field will not likely experience a

50 percent reduction in specific capacity because of on-going well testing and treatment programs.

4. INDUSTRIAL AND IRRIGATION WELLS

The procedures used to evaluate impacts to industrial and irrigation wells are different from those of other wells because well construction details and specific hydrogeologic parameters are generally unknown for the industrial and irrigation wells. In the evaluation of industrial and irrigation wells, an assumed minimum pumping water level (PWL) is determined for each well. The minimum pumping water is calculated by assuming that the maximum available drawdown is two-thirds of the initial, non-pumping saturated thickness. The value of two-thirds the saturated thickness is generally used as the maximum drawdown available in unconfined aquifers with uniform material to maintain nonturbulent flow to the well. The saturated thickness is determined from a long term run of the model at average flow conditions with no pumping.

In the evaluation of industrial and irrigation wells, the theoretical maximum yield of the well is calculated using aquifer parameters from the calibrated models and generalized well construction. The yield is calculated using a variation of the Thiem equation for steady state flow in unconfined aquifers:

$$Q = \pi \times K \left[\frac{h_0^2 - h_w^2}{\ln(r_0/r_w)} \right]$$

Q = Well yield, in gallons per day (gpd)

K = Hydraulic conductivity, in gpd/ft^2

h_o = Original saturated thickness, in feet

h_w = Saturated thickness at well, in feet

(assumed to be no less than well screen)

r_o = Distance to zero drawdown, assumed to be 1500 feet

r_w = Effective radius of well, assumed to be 1 foot

Static water levels (h_o) are obtained from the computer models operating at steady-state conditions with current river bed profiles and average flow rates. The aquifer saturated thickness is calculated by subtracting the bedrock elevation from the static water level. The minimum pumping water level (h_w) is defined as one-third the height of the saturated thickness which is accepted well design criteria. This distance is also assumed to be the screened length of the well. The minimum pumping level (h_w) is held constant for evaluation of well yields from each case.

For each case of river degradation, i.e. case 1, 2 and 3, new static water levels (h_o) are used to calculate the new theoretical yield from the well. Finally, the authorized water right rate of diversion is compared with the theoretical well yield for each case to determine the amount of apparent loss of yield.

The "losses" shown in these calculations are for general estimates only. These calculations are based on average aquifer conditions, good well construction practice, and efficient well operation. Actual impacts may vary with different local aquifer conditions, well construction and operation, and actual well efficiency. It is believed that the authorized rate of diversion for several wells is greater than the aquifer can support. However, data was not available for actual pumping rates to more accurately estimate the impacts of river degradation. These larger rates show the greatest impacts. Estimates of actual impact of individual wells will require further data collection and analysis.

C. WELL FIELD IMPACTS

1. LOWER GROUNDWATER LEVELS

General observation of data on groundwater and surface water levels and the results of groundwater computer modeling analyses confirm a strong hydrologic connection between the river and adjoining groundwater systems. Pictorial displays of typical well field groundwater impacts for Case 1, 2 and 3 conditions are shown in Figures III-2, III-3 and III-4. In all case studies, lower river levels resulted in lower groundwater levels in the well fields of major groundwater users. In general, lower groundwater levels directly affect well field operations by reducing pump capacities (through head-discharge characteristics) and by increasing energy requirements for pumping.

Because most wells are near a major source of recharge, the Kansas River, changes in river levels are almost directly reflected in groundwater level changes in the well fields. Wells some distance away from the river display less impact (for a short period of time) when the river stage drops because of recharge from soil infiltration and bank storage in the alluvium. After 30 days of low

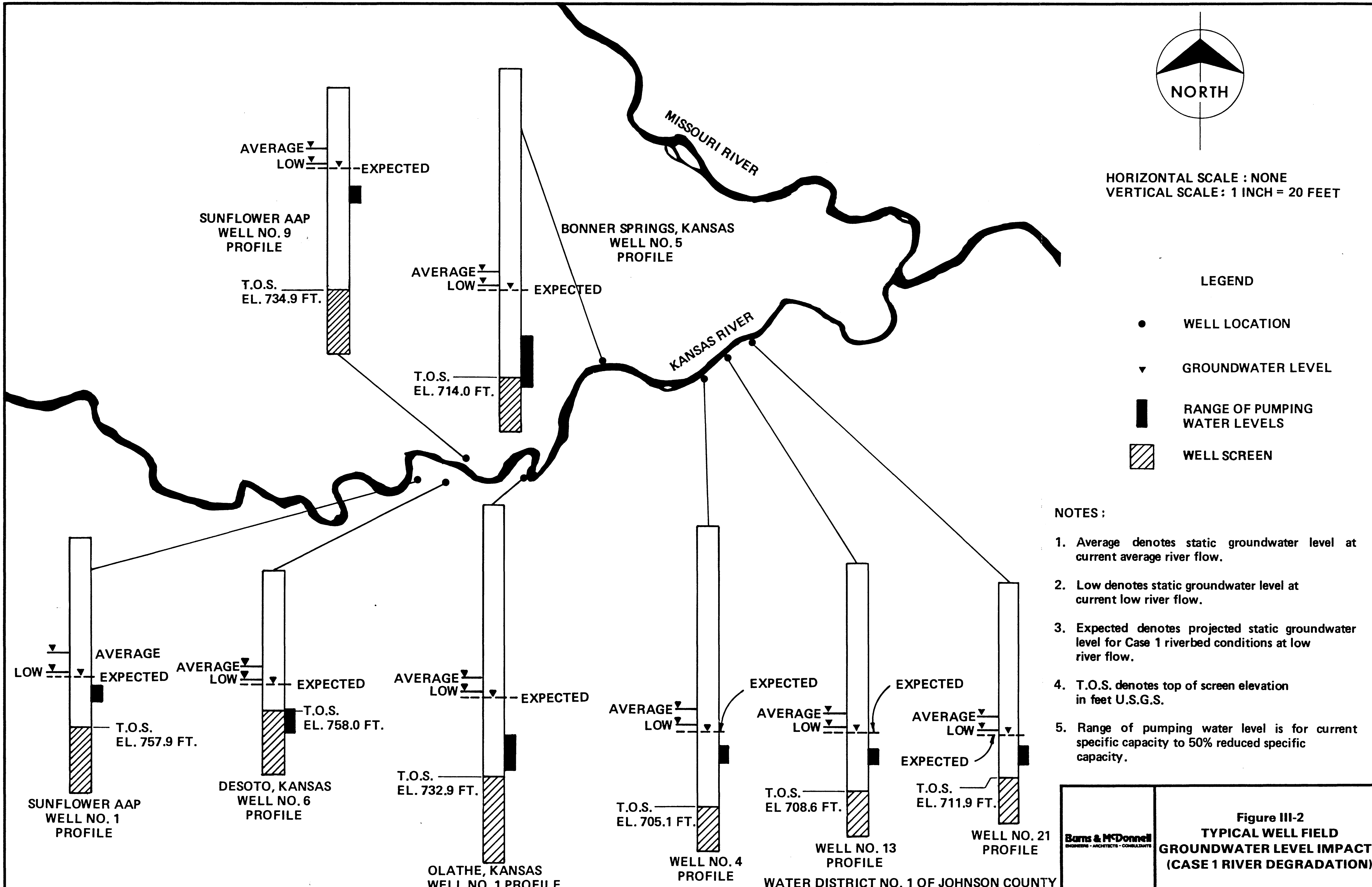
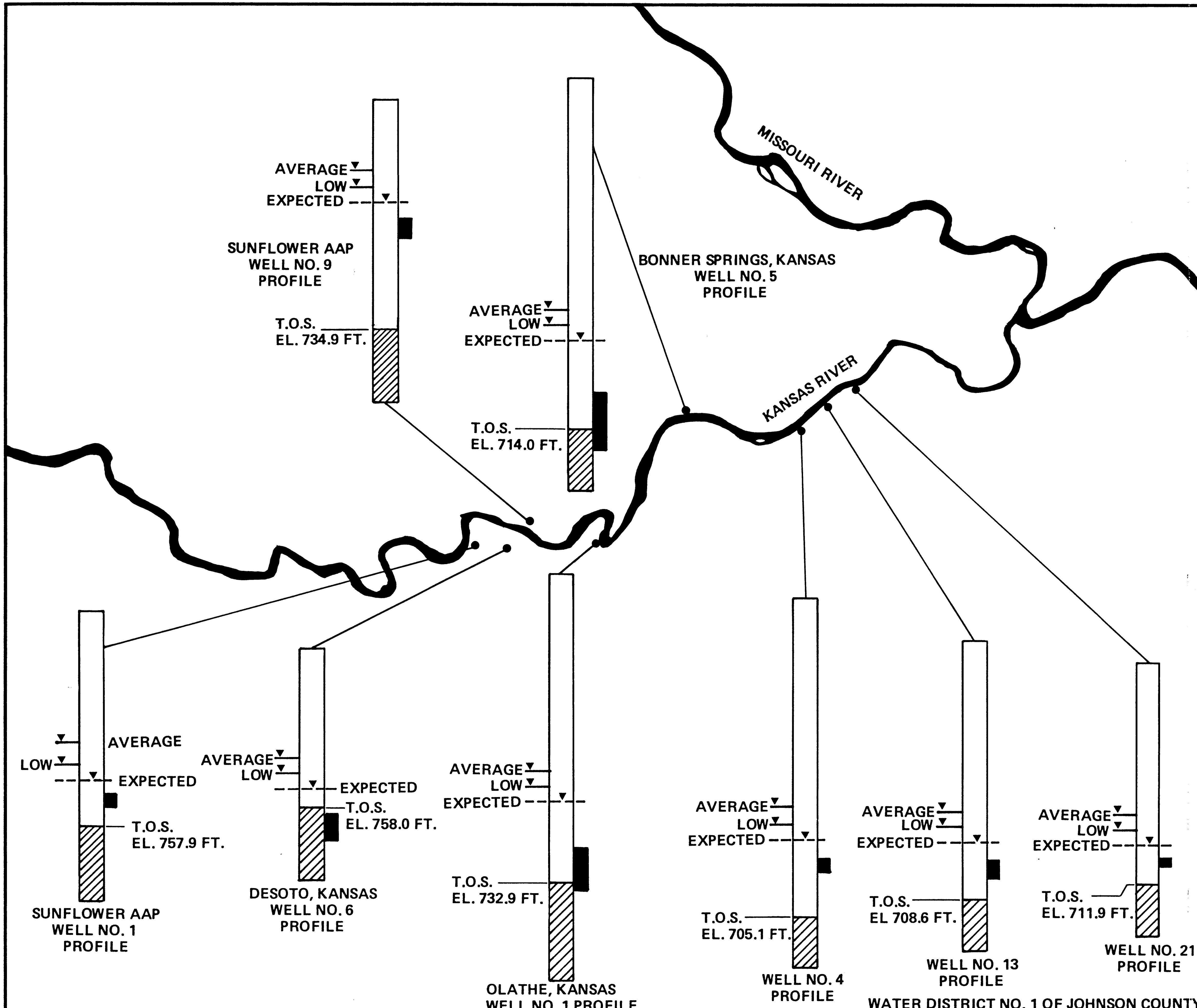
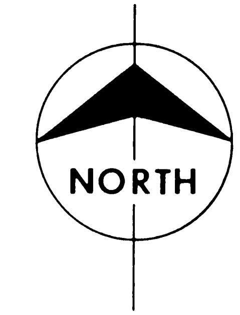


Figure III-2
TYPICAL WELL FIELD GROUNDWATER LEVEL IMPACTS (CASE 1 RIVER DEGRADATION)

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)





HORIZONTAL SCALE : NONE
VERTICAL SCALE : 1 INCH = 20 FEET

LEGEND

- ● WELL LOCATION
- ▼ GROUNDWATER LEVEL
- ▮ RANGE OF PUMPING WATER LEVELS
- ▨ WELL SCREEN

NOTES :

1. Average denotes static groundwater level at current average river flow.
2. Low denotes static groundwater level at current low river flow.
3. Expected denotes projected static groundwater level for Case 2 riverbed conditions at low river flow.
4. T.O.S. denotes top of screen elevation in feet U.S.G.S.
5. Range of pumping water level is for current specific capacity to 50% reduced specific capacity.

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Figure III-3
TYPICAL WELL FIELD GROUNDWATER LEVEL IMPACTS (CASE 2 RIVER DEGRADATION)

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

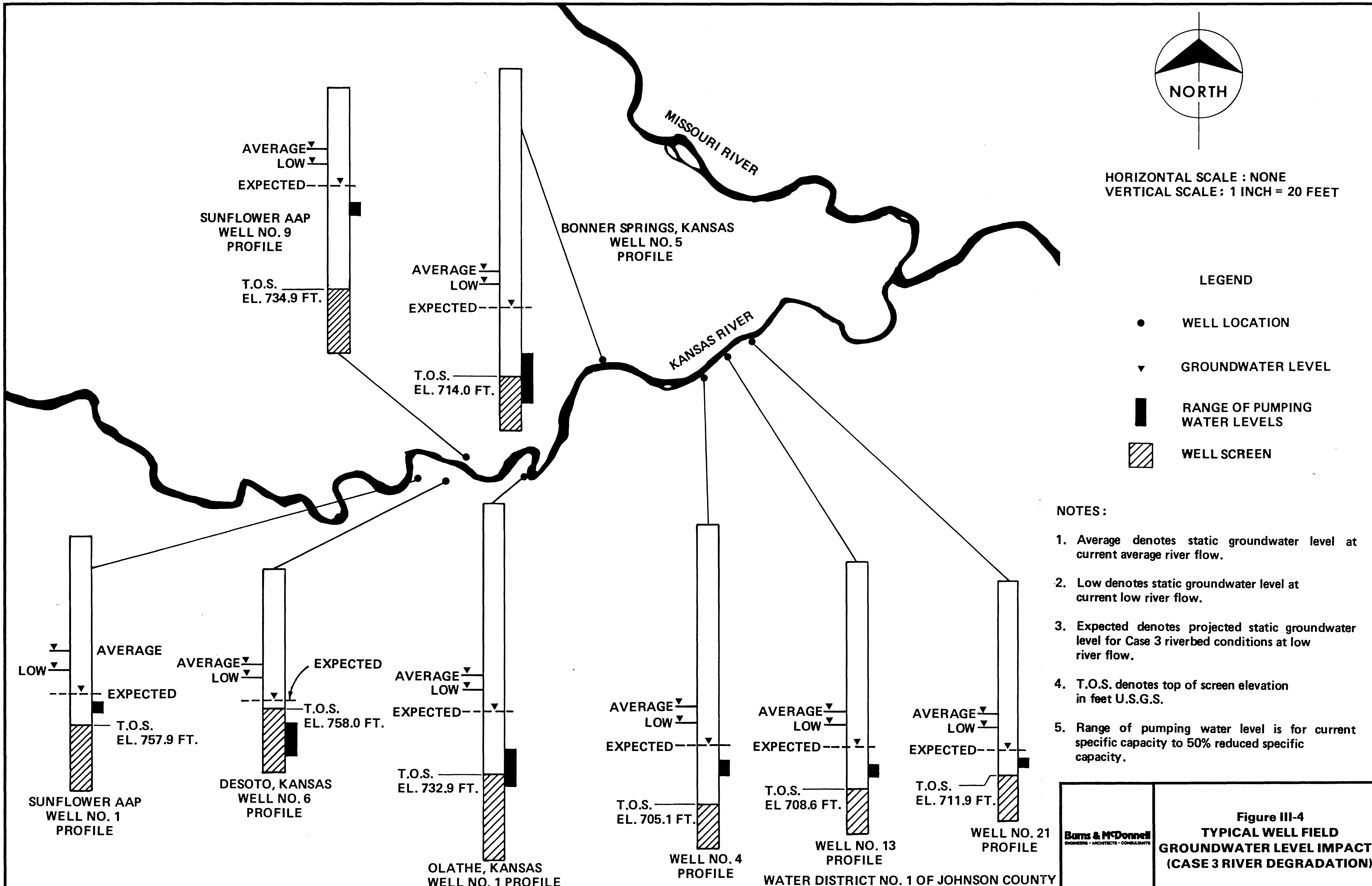

Figure III-4
TYPICAL WELL FIELD GROUNDWATER LEVEL IMPACTS (CASE 3 RIVER DEGRADATION)

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

flow conditions, most bank storage is drained into the aquifer; and, with 30 to 60 days of low flow conditions, groundwater levels generally reach steady-state conditions in the vicinity of the well fields. Examples of the variation in groundwater elevations at two nodes for varying time intervals at low flow conditions are shown in Table III-1.

Table III-1

EFFECT OF LOW FLOW DURATION ON GROUNDWATER LEVELS

Vicinity of Water District No. 1 of Johnson County, Well Field

Duration Days	No Degradation	Groundwater Elevation (feet USGS) Case 1	Case 2	Case 3
30	724.0	722.8	720.8	718.7
60	723.3	722.1	720.0	717.9
90	723.1	721.9	719.8	717.7
120	723.0	721.8	719.7	717.6
150	722.9	721.7	719.6	717.5
180	722.8	721.6	719.5	717.4

Vicinity of Bonner Springs, Kansas, Well Field

Duration Days	No Degradation	Groundwater Elevation (feet USGS) Case 1	Case 2	Case 3
30	736.0	734.6	732.5	730.4
60	735.6	734.4	732.3	730.2
180	735.6	734.4	732.3	730.2

2. <u>REDUCED WELL YIELD</u>

Reduced well yields occur in several well fields for various case studies because of reductions in saturated aquifer thicknesses caused by declining groundwater levels. By definition, the available drawdown extends from the static groundwater level to the top of well screen. When pumping rates cause actual drawdown to exceed the available drawdown, the pumping rate must be reduced to maintain the minimum PWL. Any reduction in usable saturated thickness also reduces allowable drawdown which, in turn, reduces yield.

3. <u>INCREASED OPERATING COSTS</u>

The mitigation of impacts caused by river degradation in all case studies will result in increased operating costs for all groundwater users. Basic impacts include reduced well yield and increased pumping head which may be mitigated or offset by any of three alternatives including modification of well field operation, addition of replacement wells or purchase of replacement water. Each alternative will also require increased power consumption because of higher pumping heads caused by lower groundwater levels.

Mitigation cost estimates for each well or wellfield are based on the net loss in well capacity caused by various river degradation cases, i.e. Case 1, 2 and 3. Net loss in yield is the difference between well yield at present riverbed conditions at low flow and degraded river bed condition at low flow. Several groundwater users currently experience pumping water levels below the top of well screens at present riverbed conditions during low flow. When these conditions occur, pump discharge can be throttled on the affected wells to maintain desirable pumping water levels which results in reduced well yields.

a. Alternative No. 1 - Modify Well Field Operation

Modifying the operation of a well field to produce additional water to offset lost net capacity is a possible mitigating alternative. Such operation may include:

- o Utilization of available extra capacity in the well field to make up lost capacity.
- o Operation of affected wells with pumping water levels in the well screens.

The first operating condition has little or no short term cost although the groundwater user will have a loss in the maximum overall well field capacity. The second operating condition will increase the need for well treatment to remove mineral incrustations. Increased costs for varying well field operation as used in this report are based on obtaining about 150 gpm from each of the wells in the well field. For example, if a shortage of 280 gpm exists during the water crisis, two wells will not be throttled back, but will be allowed to operate with water levels in the screen area. After the water shortage crisis passes, the well owner is assumed to immediately treat the "overused" wells (two in the above case) to recover specific capacity. The costs for treating these wells (about $7,000 for two wells) would be divided by 3 (3 year return interval on the low water duration) to determine the annual cost ($2,300 per year in this example) to be allocated for increased maintenance.

Additional power costs will affect every groundwater user because of the additional pumping head required for the three river degradation case scenarios. Power cost estimates are based on power rate information provided by groundwater users and assume a pump efficiency of 78 percent and a motor efficiency of 90 percent.

b. <u>Alternative No. 2 - Addition of Replacement Wells</u>

The addition of a replacement well(s) to offset lost well field capacity is another mitigating alternative. The construction cost of a new well is estimated to be $90,000 to $100,000 depending on well capacity. This cost estimate includes the well, well pump and motor and miscellaneous items such as a meter vault, electrical controls and access road. Additional costs of 15 percent for unknown project contingencies and 12 percent for engineering and special services are added to the construction cost estimate.

Additional power costs will also be required in this alternative because of well operation at lower groundwater levels. Assumptions for power cost estimates are the same as described for Alternative No. 1.

c. Alternative No. 3 - Replacement Water

The purchase of replacement water from an adjacent water purveyor may be a possible mitigation alternative for some groundwater users. Several factors which will influence the feasibility of this option include:

- o Purchase of replacement water will require an agreement between two entities which may not be politically acceptable to the potential purchaser because of the desire to have an independent water supply.

- o Replacement water will likely be needed at a time of high demand for the potential seller which may result in supply restrictions and high water supply charges.

The cost of replacement water developed in this study should be considered approximate and suitable only for the purpose of comparison. Actual replacement costs will vary depending on the success of negotiations for water which are beyond the scope of this investigation. Assumptions used in calculating replacement water costs include:

- o Current water rates of potential water sellers will be used.
- o Replacement water will be needed every three years (low river flow return frequency).

- o Water volume is calculated by using the replacement flow for half a day over 60 days.

- o Additional water is used continuously throughout the year to keep water in the interconnecting main "fresh".

- o Interconnecting main costs are not developed in the estimates because of lack of detailed water system hydraulic information.

Additional power costs will also be required for this alternative because of well operation at lower groundwater levels. Assumptions for cost estimates are the same as described for Alternatives No. 1 and No. 2.

d. Cost Estimates

Cost estimates are based on September, 1986 prices at an Engineering News Record Construction Cost Index (Kansas City Area) of 4450. Modified operation, pumping energy and purchase of replacement water are calculated as annual costs and the addition of a replacement well(s) is calculated as a one-time capital cost.

4. WATER DISTRICT NO. 1 OF JOHNSON COUNTY, KANSAS

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios on the well field operated by Water District No. 1 of Johnson County are shown in Tables III-2, III-3 and III-4. At present specific capacities and low river flow conditions, none of the wells have reduced yields for Case 1, 2 and 3 degradation conditions. With 50 percent reduction in specific capacities, seven wells will have reduced capacities for Case 3 conditions.

b. Mitigation

Cost estimates for various mitigation alternatives are shown in Table III-5. All alternatives are based on mitigating the impacts for Case 1, 2 and 3 degradation at present well specific capacities as shown in Tables III-2, III-3 and III-4. The provisions of additional pumping energy for well operation to offset lower groundwater levels is the only mitigation cost impact associated with this groundwater user.

Table III-2

WATER DISTRICT NO. 1 OF JOHNSON COUNTY, KANSAS
CASE 1 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	706.7	659	214	722.4	0	720.4	0	717.3	0
2	710.5	879	161	718.7	0	717.7	0	712.3	0
3	709.5	768	169	719.4	0	718.4	0	713.8	0
4	705.1	530	146	720.3	0	719.3	0	715.6	0
5	705.9	627	214	720.7	0	719.7	0	716.7	0
6	707.7	560	90	717.4	0	716.4	0	710.2	0
7	709.3	502	89	718.2	0	717.2	0	711.5	0
8	709.1	441	65	717.0	0	716.0	0	709.2	0
9		0							
10	708.8	375	70	718.5	0	717.5	0	712.2	0
11	711.0	164	68	712.2	0	720.2	0	717.8	0
12	711.4	263	51	718.3	0	717.3	0	712.2	0
13	708.6	203	58	719.6	0	718.6	0	715.1	0
14	710.9	314	56	717.8	0	716.8	0	711.2	0
15	709.6	144	48	720.2	0	719.2	0	716.2	0
16	707.9	339	0						
17	708.0	137	84	720.9	0	720.0	0	718.3	0
18	709.6	72	69	721.5	0	720.6	0	719.5	0
19	712.0	66	49	721.4	0	720.4	0	719.0	0
20	712.0	167	74	720.0	0	719.0	0	716.8	0
21	711.9	127	70	720.5	0	719.5	0	717.7	0
	Total:	7337		Total:	0	Total:	0		

Table III-3

WATER DISTRICT NO. 1 OF JOHNSON COUNTY, KANSAS
CASE 2 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	706.7	659	214	722.4	0	718.5	0	715.4	0
2	710.5	879	161	718.7	0	715.8	0	710.4	0
3	709.5	768	169	719.4	0	716.5	0	711.9	0
4	705.1	530	146	720.3	0	717.4	0	713.7	0
5	705.9	627	214	720.7	0	717.8	0	714.8	0
6	707.7	560	90	717.4	0	714.5	0	708.3	0
7	709.3	502	89	718.2	0	715.2	0	709.5	0
8	709.1	441	65	717.0	0	714.0	0	707.2	0
9		0							
10	708.8	375	70	718.5	0	715.6	0	710.3	0
11	711.0	164	68	712.2	0	718.2	0	715.8	0
12	711.4	263	51	718.3	0	715.3	0	710.2	0
13	708.6	203	58	719.6	0	716.6	0	713.1	0
14	710.9	314	56	717.8	0	714.8	0	709.2	0
15	709.6	144	48	720.2	0	717.2	0	714.2	0
16	707.9	339	0						
17	708.0	137	84	720.9	0	718.0	0	716.3	0
18	709.6	72	69	721.5	0	718.6	0	717.5	0
19	712.0	66	49	721.4	0	718.4	0	717.0	0
20	712.0	167	74	720.0	0	717.0	0	714.8	0
21	711.9	127	70	720.5	0	717.5	0	715.7	0
	Total:	7337		Total:	0	Total:	0		

Table III-4

WATER DISTRICT NO. 1 OF JOHNSON COUNTY, KANSAS
CASE 3 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	706.7	659	214	722.4	0	716.7	0	713.6	0
2	710.5	879	161	718.7	0	714.0	0	708.6	-154
3	709.5	768	169	719.4	0	714.5	0	709.9	0
4	705.1	530	146	720.3	0	715.4	0	711.7	0
5	705.9	627	214	720.7	0	715.9	0	712.9	0
6	707.7	560	90	717.4	0	712.6	0	706.4	-60
7	709.3	502	89	718.2	0	713.3	0	707.6	-75
8	709.1	441	65	717.0	0	712.1	0	705.3	-122
9		0							
10	708.8	375	70	718.5	0	713.7	0	708.4	-14
11	711.0	164	68	712.2	0	716.3	0	713.9	0
12	711.4	263	51	718.3	0	713.4	0	708.3	-79
13	708.6	203	58	719.6	0	714.7	0	711.2	0
14	710.9	314	56	717.8	0	712.9	0	707.3	-101
15	709.6	144	48	720.2	0	712.1	0	712.3	0
16	707.9	339	0						
17	708.0	137	84	720.9	0	716.1	0	714.4	0
18	709.6	72	69	721.5	0	716.7	0	715.6	0
19	712.0	66	49	721.4	0	716.6	0	715.2	0
20	712.0	167	74	720.0	0	715.1	0	712.9	0
21	711.9	127	70	720.5	0	715.6	0	713.8	0
	Total:	7337		Total:	0	Total:	0		

Table III-5

WATER DISTRICT NO. 1 OF JOHNSON COUNTY, KANSAS
IMPACT MITIGATION COST ESTIMATES[1]

Item	River Degradation Condition		
	Case 1	Case 2	Case 3
Alternative No. 1:			
a. Modify Well Field Operation	NR	NR	NR
b. Additional Pumping Energy	$200	$600	$1,000
Total:	$200	$600	$1,000
Alternative No. 2:			
a. Add Replacement Well	NR	NR	NR
b. Additional Pumping Energy	$200	$600	$1,000
Total:	$200	$600	$1,000
Alternative No. 3:			
a. Purchase Replacement Water	NR	NR	NR
b. Additional Pumping Energy	$200	$600	$1,000
Total:	$200	$600	$1,000

NOTES:

1. Costs based on September, 1986 prices; modified operation, additional pumping energy and replacement water are annual costs; replacement well(s) are one-time capital costs.
2. NR denotes alternative is not required for case condition indicated.

5. BONNER SPRINGS, KANSAS

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios on the Bonner Springs well field are shown in Tables III-6, III-7 and III-8. At present specific capacities and low river flow conditions, none of the wells have reduced yields for Case 1, 2 and 3 river degradation conditions. With 50 percent reduction in specific capacities at low flow conditions, one well will have reduced capacity for Case 1 conditions and two wells will have reduced capacities for Case 2 and 3 conditions.

b. Mitigation

Cost estimates for various mitigation alternatives are shown in Table III-9. All alternatives are based on mitigating the impacts of Case 1, 2 and 3 degradation at present specific capacities as shown in Tables III-6, III-7 and III-8. The provision of additional pumping energy for well operation to offset lower groundwater levels is the only mitigation cost impact associated with this groundwater users.

Table III-6

BONNER SPRINGS, KANSAS
CASE 1 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	719.0	300	26	724.5	0	723.5	0	711.9	0
2A	720.0	350	65	730.9	0	729.9	0	724.5	0
3	719.0	320	39	728.1	0	727.1	0	718.9	-2
4	719.0	400	70	730.5	0	729.5	0	724.5	0
5	714.0	425	74	729.8	0	728.8	0	723.0	0
	Total:	1795		Total:	0	Total:	0		

Table III-7

BONNER SPRINGS, KANSAS
CASE 2 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	719.0	300	26	724.5	0	721.5	0	709.9	-118
2A	720.0	350	65	730.9	0	727.9	0	722.5	0
3	719.0	320	39	728.1	0	725.1	0	716.9	-41
4	719.0	400	70	730.5	0	727.5	0	722.5	0
5	714.0	425	74	729.8	0	726.8	0	721.0	0
	Total:	1795		Total:	0	Total:	0		

Table III-8

BONNER SPRINGS, KANSAS
CASE 3 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	719.0	300	26	724.5	0	719.5	0	707.9	-144
2A	720.0	350	65	730.9	0	725.9	0	720.5	0
3	719.0	320	39	728.1	0	723.1	0	714.9	-80
4	719.0	400	70	730.5	0	725.5	0	720.5	0
5	714.0	425	74	729.8	0	724.8	0	719.0	0
	Total:	1795		Total:	0	Total:	0		

Table III-9

BONNER SPRINGS, KANSAS
IMPACT MITIGATION COST ESTIMATES[1]

Item	River Degradation Condition		
	Case 1	Case 2	Case 3
Alternative No. 1:			
a. Modify Well Field Operation	NR	NR	NR
b. Additional Pumping Energy	$100	$300	$500
Total:	$100	$300	$500
Alternative No. 2:			
a. Add Replacement Well	NR	NR	NR
b. Additional Pumping Energy	$100	$300	$500
Total:	$100	$300	$500
Alternative No. 3:			
a. Purchase Replacement Water	NR	NR	NR
b. Additional Pumping Energy	$100	$300	$500
Total:	$100	$300	$500

NOTES:

1. Costs based on September, 1986 prices; modified operation additional pumping energy, and replacement water are annual costs; replacement well(s) are one-time capital costs.

2. NR denotes alternative not required for case condition indicated.

6. OLATHE, KANSAS

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios on the Olathe well field are shown in Tables III-10, III-11 and III-12. At present specific capacities and low river flow conditions, four wells will have reduced yields totalling 1002 gpm. For the Case 1 condition, four wells will have reduced yields totalling 1349 gpm (a net decrease of 347 gpm). For the Case 2 condition, five wells will have reduced yields totalling 1754 gpm (a net decrease of 752 gpm). For the Case 3 condition, six wells will have reduced yields totalling 2010 gpm (a net decrease of 1008 gpm). With 50 percent reduction in specific capacities at low flow conditions, eight wells will have reduced capacities for Case 1 conditions, and all eleven wells will have reduced capacities for Case 2 and 3 conditions.

b. Mitigation

Cost estimates of various mitigation alternatives are shown in Table III-13. All alternatives are based on mitigating the impacts of Case 1, 2 and 3 at present well specific capacities as shown in Tables III-10, III-11 and III-12.

Table III-10

OLATHE, KANSAS
CASE 1 IMPACT ON WELL FIELD PRODUCTION

Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Present River Conditions Low Flow: Estimated PWL	Present River Conditions Low Flow: Reduced Discharge (GPM)	Impact at Present Specific Capacity: Estimated PWL	Impact at Present Specific Capacity: Reduced Discharge (GPM)	Impact at 50% Reduction in Present Specific Capacity: Estimated PWL	Impact at 50% Reduction in Present Specific Capacity: Reduced Discharge (GPM)
1	732.9	500	59	743.4	0	742.4	0	733.8	0
2	737.0	500	69	744.0	0	743.0	0	735.7	-43
3	740.6	300	51	746.0	0	744.9	0	738.9	-42
4	742.7	300	46	744.6	0	743.5	0	737.0	-131
5	739.0	500	97	746.6	0	745.7	0	740.5	0
6	739.0	700	88	743.2	0	742.2	0	734.3	-207
7	750.1	500	102	746.3	-388	745.3	-490	740.4	-495
8	749.0	500	78	744.1	-383	743.1	-461	736.7	-480
9	748.5	500	114	746.9	-182	745.9	-295	741.5	-398
10	742.8	500	54	741.9	-50	740.9	-103	731.5	-302
11	742.8	500	135	748.2	0	747.2	0	743.5	0
	Total:	5300		Total:	-1002	Total:	-1349		

Table III-11

OLATHE, KANSAS
CASE 2 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	732.9	500	59	743.4	0	740.5	0	731.9	-28
2	737.0	500	69	744.0	0	741.1	0	733.8	-109
3	740.6	300	51	746.0	0	743.1	0	737.1	-88
4	742.7	300	46	744.6	0	741.6	-49	735.1	-174
5	739.0	500	97	746.6	0	743.8	0	738.6	-17
6	739.0	700	88	743.2	0	740.3	0	732.4	-291
7	750.1	500	102	746.3	-388	743.4	-500	738.5	-500
8	749.0	500	78	744.1	-383	741.2	-500	734.8	-500
9	748.5	500	114	746.9	-182	744.0	-500	739.6	-500
10	742.8	500	54	741.9	-50	739.0	-205	729.6	-353
11	742.8	500	135	748.2	0	745.3	0	741.6	-81
	Total:	5300		Total:	-1002	Total:	-1754		

Table III-12

OLATHE, KANSAS
CASE 3 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	732.9	500	59	743.4	0	738.6	0	730.0	-84
2	737.0	500	69	744.0	0	739.1	0	731.8	-178
3	740.6	300	51	746.0	0	741.1	0	735.1	-138
4	742.7	300	46	744.6	0	739.6	-140	733.1	-220
5	739.0	500	97	746.6	0	741.8	0	736.6	-114
6	739.0	700	88	743.2	0	738.3	-58	730.4	-379
7	750.1	500	102	746.3	-388	741.4	-500	736.5	-500
8	749.0	500	78	744.1	-383	739.1	-500	732.8	-500
9	748.5	500	114	746.9	-182	742.0	-500	737.6	-500
10	742.8	500	54	741.9	-50	737.0	-312	727.6	-406
11	742.8	500	135	748.2	0	743.3	0	739.6	-216
	Total:	5300		Total:	-1002	Total:	-2010		

Cost estimates for Alternative No. 1 include additional power costs and additional well treatment costs to offset well operation with drawdown in the well screens.

Cost estimates for Alternative No. 2 include additional power costs and the addition of one replacement well for Case 1 and 2 conditions and two wells for the Case 3 condition.

Cost estimates for Alternative No. 3 include additional power costs and the purchase of replacement water from Water District No. 1 of Johnson County, Kansas.

Table III-13

OLATHE, KANSAS
IMPACT MITIGATION COST ESTIMATES[1]

Item	River Case 1	Degradation Case 2	Condition Case 3
Alternative No. 1:			
a. Modify Well Field Operation	$2,800	$6,900	$9,600
b. Additional Pumping Energy	400	1,100	1,800
Total:	$3,200	$8,000	$11,400
Alternative No. 2:			
a. Add Replacement Well(s)	$112,000	$ 125,000	$ 237,000
b. Additional Pumping Energy	400	1,100	1,800
Total:	$112,400	$ 126,100	$ 238,800
Alternative No. 3:			
a. Purchase Replacement Water	$33,000	$ 42,000	$ 47,000
b. Additional Pumping Energy	400	1,100	1,800
Total:	$33,400	$ 43,100	$ 48,800

NOTES:

1. Costs based on September, 1986 prices; modified well operation, additional pumping energy and replacement water are annual costs; replacement well(s) are one-time costs.

7. DESOTO, KANSAS

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios on the DeSoto well field are shown in Tables III-14, III-15 and III-16. At present specific capacities and low river flow conditions, one well will have a reduced yield of 249 gpm. For the Case 1 conditions, one well will have reduced yield of 273 gpm (a net reduction of 24 gpm). For the Case 2 condition, two wells will have reduced yields totalling 380 gpm (a net reduction of 131 gpm). For the Case 3 condition, two wells will have reduced yields totalling 513 gpm (a net reduction of 264 gpm). With 50 percent reduction in specific capacities at low flow conditions, one well will have reduced yield for the Case 1 condition and, two wells will have reduced yield for the Case 2 and Case 3 conditions.

b. Mitigation

Cost estimates of various mitigation alternatives are shown in Table III-17. All alternatives are based on mitigating the impacts of Case 1, 2 and 3 degradations at present well specific capacities as shown in Tables III-14, III-15 and III-16.

Table III-14

DESOTO, KANSAS
CASE 1 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
3	737.3	298	41	755.8	0	754.8	0	747.6	0
4	738.0	304	42	755.9	0	754.9	0	747.6	0
5	758.0	356	26	748.4	-249	747.5	-273	N.O.	-356
6	758.0	300	55	759.5	0	758.6	0	753.2	0
	Total:	1258		Total:	-249	Total:	-273		

Notes:

1. N.O. denotes not operable at this condition.

Table III-15

DESOTO, KANSAS
CASE 2 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
3	737.3	298	41	755.8	0	753.0	0	745.8	0
4	738.0	304	42	755.9	0	753.1	0	745.8	0
5	758.0	356	26	748.4	-249	745.6	-322	N.O.	-356
6	758.0	300	55	759.5	0	756.9	-58	751.5	-179
	Total:	1258		Total:	-249	Total:	-380		

Notes:

1. N.O. denotes not operable at this condition.

Table III-16

DESOTO, KANSAS
CASE 3 IMPACT ON WELL FIELD PRODUCTION

Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Present River Conditions Low Flow: Estimated PWL	Present River Conditions Low Flow: Reduced Discharge (GPM)	Impact at Present Specific Capacity: Estimated PWL	Impact at Present Specific Capacity: Reduced Discharge (GPM)	Impact at 50% Reduction in Present Specific Capacity: Estimated PWL	Impact at 50% Reduction in Present Specific Capacity: Reduced Discharge (GPM)
3	737.3	298	41	755.8	0	751.2	0	744.0	0
4	738.0	304	42	755.9	0	751.2	0	744.0	0
5	758.0	356	26	748.4	-249	743.7	-356	N.O.	-356
6	758.0	300	55	759.5	0	755.1	-157	747.7	-228
	Total:	1258		Total:	-249	Total:	-513		

Notes:

1. N.O. denotes not operable at this condition

Cost estimates for Alternative No. 1 include additional power costs and additional well treatment to offset well operation with drawdown in the well screens for Case 1 and 2 conditions. No cost is shown for the Case 3 condition because modified well field operation will not produce sufficient yield to meet demand under this operating scenario. Cost estimates for Alternative

Table III-17

DESOTO, KANSAS
IMPACT MITIGATION COST ESTIMATES[1]

Item	River Degradation Condition Case 1	Case 2	Case 3
Alternative No. 1:			
a. Modify Well Field Operation	$1,200	$2,000	NF-1
b. Additional Pumping Energy	100	200	$ NF-1
Total:	$1,300	$2,500	$ NF-1
Alternative No. 2:			
a. Add Replacement Well	$112,000	$112,000	$112,000
b. Additional Pumping Energy	100	200	300
Total:	$112,100	$112,200	$112,300
Alternative No. 3:			
a. Purchase Replacement Water	NF-2	NF-2	NF-2
b. Additional Pumping Energy	NF-2	NF-2	NF-2
Total:	NF-2	NF-2	NF-2

NOTES:

1. Costs based on September, 1986 prices; modified operation additional pumping energy and replacement water are annual costs; replacement well(s) are one-time costs.

2. NF-1 denotes alternative is not feasible because modified well operation will not offset well production loss due to degradation.

3. NF-2 denotes alternatives not feasible because no nearby water purveyor is available to supply water at reasonable cost.

No. 2 include additional power costs and the addition of one replacement well. Alternative No. 3 has no cost estimate because nearby water purveyors are not available to supply replacement water at reasonable cost.

8. SUNFLOWER ARMY AMMUNITION PLANT (SAAP)

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios on the SAAP well field are shown in Tables III-18, III-19 and III-20. At present specific capacities and low river flow conditions, none of the wells will experience any reduction in yield. For Case 1, 2 and 3 conditions, none of the wells have any reduction in yield. With 50 percent reduction in specific capacities at low flow conditions, one well will have reduced yields for Case 1, 2 and 3 conditions.

b. Mitigation

Cost estimates for various mitigation alternatives are shown in Table III-21. Well field capacity is not significantly impacted in any of the case studies. The provision of additional pumping energy for well operation to offset lower groundwater levels is the only mitigation cost impact associated with this groundwater user.

Table III-18

SUNFLOWER ARMY AMMUNITION PLANT
CASE 1 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	757.9	86	35	768.0	0	767.1	0	764.7	0
2	759.9	0							
3	755.4	60	45	767.7	0	767.0	0	765.7	0
4	750.6	0							
5	759.3								
6	749.4	84	22	765.4	0	764.8	0	761.1	0
7	744.5	258	40	757.4	0	757.0	0	750.6	0
8	744.5	156	25	758.9	0	757.9	0	751.6	0
9	734.9	255	67	760.2	0	759.2	0	755.3	0
10	737.2	207	68	761.0	0	760.0	0	756.9	0
11	743.9	199	25	756.6	0	755.6	0	747.7	0
12	742.8	185	16	752.7	0	751.7	0	739.9	-23
	Total:	1490		Total:	0	Total:	0		

Table III-19

SUNFLOWER ARMY AMMUNITION PLANT
CASE 2 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	757.9	86	35	768.0	0	765.2	0	762.8	0
2	759.9	0							
3	755.4	60	45	767.7	0	765.2	0	763.9	0
4	750.6	0							
5	759.3								
6	749.4	84	22	765.4	0	763.1	0	759.4	0
7	744.5	258	40	757.4	0	755.2	0	748.8	0
8	744.5	156	25	758.9	0	756.5	0	750.2	0
9	734.9	255	67	760.2	0	757.6	0	753.7	0
10	737.2	207	68	761.0	0	758.6	0	755.5	0
11	743.9	199	25	756.6	0	754.3	0	746.4	0
12	742.8	185	16	752.7	0	750.5	0	738.7	-32
	Total:	1490		Total:	0	Total:	0		

Table III-20

SUNFLOWER ARMY AMMUNITION PLANT
CASE 3 IMPACT ON WELL FIELD PRODUCTION

				Present River Conditions Low Flow		Impact at Present Specific Capacity		Impact at 50% Reduction in Present Specific Capacity	
Well Number	Minimum Acceptable Water Level	Present Pump Discharge (GPM)	Present Specific Capacity	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)	Estimated PWL	Reduced Discharge (GPM)
1	757.9	86	35	768.0	0	763.4	0	761.0	0
2	759.9	0							
3	755.4	60	45	767.7	0	763.4	0	762.1	0
4	750.6	0							
5	759.3								
6	749.4	84	22	765.4	0	761.4	0	757.7	0
7	744.5	258	40	757.4	0	753.5	0	747.1	0
8	744.5	156	25	758.9	0	754.8	0	748.5	0
9	734.9	255	67	760.2	0	755.2	0	751.9	0
10	737.2	207	68	761.0	0	757.0	0	753.9	0
11	743.9	199	25	756.6	0	752.7	0	744.8	0
12	742.8	185	16	752.7	0	748.9	0	737.1	-45
	Total:	1490		Total:	0	Total:	0		

Table III-21

SUNFLOWER ARMY AMMUNITION PLANT
IMPACT MITIGATION COST ESTIMATES[1]

Item	River Degradation Condition		
	Case 1	Case 2	Case 3
Alternative No. 1:			
a. Modify Well Field Operation	NR	NR	NR
b. Additional Pumping Energy	$300	$900	$1,500
Total:	$300	$900	$1,500
Alternative No. 2:			
a. Add Replacement Well(s)	NR	NR	NR
b. Additional Pumping Energy	$300	$900	$1,500
Total:	$300	$900	$1,500
Alternative No. 3:			
a. Purchase Replacement Water	NR	NR	NR
b. Additional Pumping Energy	$300	$900	$1,500
Total:	$300	$900	$1,500

NOTES:

1. Costs based on September, 1986 prices; modified operation, additional pumping energy and replacement water are annual costs; replacement well(s) are one-time capital costs.

2. NR denotes alternative is not required for case condition indicated.

9. MISCELLANEOUS INDUSTRIAL AND IRRIGATION WELLS

a. Impacts

The impacts of Case 1, 2 and 3 river degradation scenarios for industrial and irrigation wells in Groundwater Model Areas 1, 2 and 3 are respectively shown in Tables III-22, III-23 and III-24. The calculation of impacts for industrial and irrigation differs from the calculation of impacts to the five major well fields because of the lack of well construction details, water level information, and actual pumping rates.

The general procedures used to calculate impacts include:

- o Determination of current saturated thickness and generalized construction at each well.
- o Calculation of theoretical maximum yield for each well.
- o Computation of theoretical maximum yield for each river degradation case.
- o Comparison of authorized rates of diversion with calculated maximum theoretical yield.

Using these assumptions, two wells have reduced yields totalling 156 gpm with current riverbed conditions. For the Case 1 condition, three wells will have reduced yields totalling 272 gpm (a net reduction of 116 gpm). For the Case 2 condition, four wells will have reduced yields totalling 604 gpm (a net reduction of 448 gpm). For the Case 3 condition, five wells will have reduced yields totalling 1,048 gpm (a net reduction of 892 gpm). Because of the general lack of data, no calculations are made for reduced well yields at a 50 percent reduction in specific capacities.

Table III-25 summarizes the industrial and irrigation well yield reductions determined by comparing the theoretical yield for the various cases with the authorized amount. The "losses" shown in these calculations are general estimates only. These calculations are based on average aquifer conditions, good well construction practice, and efficient well operation. Actual impacts may vary because of local aquifer conditions, actual well construction and operation, and actual well efficiency.
The authorized rate of diversion for several wells is believed to be greater than the aquifer can support. The use of larger flow rates will show the greatest impacts to well yields. Data are not available on actual pumping rates to more accurately estimate the impacts of river degradation. Acquisition of such information will require collection and analysis of actual well data which is beyond the scope of this work.

Table III-22

MODEL 1 INDUSTRIAL AND IRRIGATION WELLS
CASE 1, 2, 3 IMPACTS ON WELL PRODUCTION

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Authorized Discharge Rate (gpm)	Reduction Required (gpm)
No. 1762	0	-31	31	10.3	765	400	---
No. 37092	-2	-19	17	5.7	230	20	---
No. 35592	2.4	-27	29.4	9.8	688	650	---
No. 35593	2.3	-24	26.3	8.8	550	250	---

Case 1

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 1762	-1	-31	30.0	10.3	710	-
No. 37092	-3	-19	16.0	5.7	200	-
No. 35592	1.4	-27	28.4	9.8	636	14
No. 36693	1.3	-24	25.3	8.8	504	-

Case 2

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 1762	-3	-31	28.0	10.3	606	-
No. 37092	-5	-19	14.0	5.7	147	-
No. 35592	-0.6	-27	26.4	9.8	538	112
No. 36693	-0.7	-24	23.3	8.8	417	-

Case 3

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 1762	-5	-31	26.0	10.3	509	-
No. 37092	-7	-19	12.0	5.7	130	-
No. 35592	-2.6	-27	24.4	9.8	447	203
No. 36693	-2.7	-24	21.3	8.8	337	-

Table III-23

MODEL 2 INDUSTRIAL AND IRRIGATION WELLS
CASE 1, 2, 3 IMPACTS ON WELL PRODUCTION

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Authorized Discharge Rate (gpm)	Reduction Required (gpm)
No. WY001V*	-3.8	-35	31.2	10.4	774	600 (total)*	---
No. 36216	-4.6	-35	30.4	10.1	735	100	---
No. 10125	8.1	-13	21.1	7.0	354	420	66
No. 6849	-1.4	-27	25.6	8.5	521	360	---

Case 1

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. WY001V*	-4.8	-35	30.2	10.4	719	-
No. 36216	-5.6	-35	29.4	10.1	682	-
No. 10125	7.1	-13	20.1	7.0	317	103
No. 6849	-2.4	-27	24.6	8.5	476	-

Case 2

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. WY001V*	-6.8	-35	28.2	10.4	615	-
No. 36216	-7.6	-35	27.4	10.1	580	-
No. 10125	5.1	-13	18.1	7.0	249	171
No. 6849	-4.4	-27	22.6	8.5	392	-

Case 3

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. WY001V*	-8.8	-35	26.2	10.4	518	--
No. 36216	-9.6	-35	25.4	10.1	486	--
No. 10125	3.1	-13	16.1	7.0	188	232
No. 6849	-6.4	-27	20.6	8.5	315	45

* Includes 2 wells and Water Right Nos. 5144 and 33076. Each well is pumping 250-300 gpm.

Table III-24

MODEL 3 INDUSTRIAL AND IRRIGATION WELLS
CASE 1, 2, 3 IMPACTS ON WELL PRODUCTION

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Authorized Discharge Rate (gpm)	Reduction Required (gpm)
No. 28892	4.5	-40	44.5	14.8	1575	1000	-
No. 28899(a)	0.7	-40	40.7	13.6	1318	1150	-
No. 28899(b)	0.5	-36	36.5	12.2	1060	1150	90
No. 9730	-8.9	-50	41.1	13.7	1344	355	-
No. 6594	-10.4	-47	36.6	12.2	1066	330	-

Case 1

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 28892	3.5	-40	43.5	14.8	1497	-
No. 28899(a)	-0.3	-40	39.7	13.6	1246	-
No. 28899(b)	-0.5	-36	35.5	12.2	995	155
No. 9730	-9.9	-50	40.1	13.7	1271	-
No. 6594	-11.4	-47	35.6	12.2	1001	-

Case 2

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 28892	1.5	-40	41.5	14.8	1344	-
No. 28899(a)	-2.3	-40	37.7	13.6	1107	43
No. 28899(b)	-2.5	-36	33.5	12.2	872	278
No. 9730	-11.9	-50	38.1	13.7	1131	-
No. 6594	-13.4	-47	33.6	12.2	877	-

Case 3

Well	Model Head (Elev-Ft.)	Bedrock Elevation (Elev-Ft.)	Saturated Thickness (Feet)	Theoretical Screen Length (Feet)	Theoretical Well Yield (gpm)	Reduction Required (gpm)
No. 28892	-0.5	-40	39.5	14.8	1199	-
No. 28899(a)	-4.3	-40	35.7	13.6	976	174
No. 28899(b)	-4.5	-36	31.5	12.2	756	394
No. 9730	-13.9	-50	36.1	13.7	998	-
No. 6594	-15.4	-47	31.6	12.2	760	-

Table III-25

SUMMARY OF INDUSTRIAL AND IRRIGATION WELLS YIELD REDUCTIONS
(THEORETICAL YIELD COMPARED TO AUTHORIZED AMOUNT)

Model Area 1
Reduction in Theoretical
Well Yields (gpm)

Well	Present	Case 1	Case 2	Case 3
No. 1762	-	-	-	-
No. 37092	-	-	-	-
No. 35592	-	14	112	203
No. 35593	-	-	-	-

Model Area 2
Reduction in Theoretical
Well Yields (gpm)

Well	Present	Case 1	Case 2	Case 3
No. WY001-V*	-	-	-	-
No. 36216	-	-	-	-
No. 10125	66	103	171	232
No. 6849	-	-	-	45

Model Area 3
Reduction in Theoretical
Well Yields (gpm)

Well	Present	Case 1	Case 2	Case 3
No. 28892	-	-	-	-
No. 28899(a)	-	-	43	174
No. 28899(b)	90	155	278	394
No. 9730	-	-	-	-
No. 6594	-	-	-	-

* Includes 2 wells and Water Right Nos. 5144 and 33076.

b. Mitigation

Cost estimates for various mitigation alternatives are shown in Table III-26. All alternatives are based on mitigating the impacts of Case 1, 2 and 3 degradation as shown in Tables III-22, III-23 and III-24. The need for additional pumping energy for well operation to offset lower groundwater levels is considered neglible in all cases. Cost estimates for Alternative No. 1 include additional well treatment to offset well operation with drawdown in the well screens for Case 1, 2 and 3 conditions. Cost estimates for Alternative No. 2 include the additions of one replacement well for the Case 1 condition, three replacement wells for the Case 2 condition and six replacement wells for the Case 3 condition. No cost estimates are made for Alternative No. 3 because the purchase of replacement water is not considered feasible for industrial and irrigation wells because of high costs.

10. CONCLUSIONS

Groundwater system impacts are determined using computer-derived groundwater levels and manual computations using site-specific well operating data. Impacts are determined for Case 1 (1 foot), Case 2 (3 feet) and Case 3 (5 feet) river degradation at low river flow conditions (less than 1000 cfs discharge). Impacts are determined based on projected pumping water levels, use of the top of well screens as the minimum acceptable pumping levels operation, and application of specific capacity data to determine impacts to well operation.

Table III-26
MISCELLANEOUS INDUSTRIAL AND IRRIGATION WELLS
IMPACT MITIGATION COST ESTIMATES

River Degradation Case	Model Area	Well User I.D.	Net Additional Water Required (gpm)	Alternative 1 Modify Well Field Operation	Alternative 2 Add Replacement Well	Alternative 3[4] Purchase Replacement Water
1	1	35592	14	$1,200	$112,000	--
1	2	10125	37	1,200	112,000	--
1	3	28899 (b)	65	1,200	112,000	--
				$3,600	$336,000	--
2	1	35592	112	1,200	112,000	--
2	2	10125	105	1,200	112,000	--
2	3	28899 (a+b)	231	2,400	112,000	--
				$4,800	$336,000	--
3	1	35592	203	NF	112,000	--
3	2	6849	45	1,200	112,000	--
3	2	10125	166	1,200	112,000	--
3	3	28899 (a+b)	478	NF	125,000	--
				$2,400 [6]	$461,000	--

NOTES:
1. Costs are based on September, 1986 prices; modified well operation is an annual cost; replacement well(s) are one-time costs.
2. Additional pumping energy costs are neglible for all industrial and irrigation users; for Case 3 conditions, additional power costs of only about $45 per year are required for all well users.
3. No well users are impacted.
4. Alternative 3 is not considered because of lack of detailed information on alternative water sources.
5. NF denotes alternative is not feasible because modified well operation will not offset well production loss due to degradation.
6. Cost does not include all wells because modification of operation was not feasible for all wells.

General well field impacts include lower groundwater levels which result in higher groundwater pumping heads and lower well yields because of reduction in aquifer saturated thickness. Both impacts generally result in increased costs of well field operation.

Three alternatives for mitigating the impacts of various river degradation scenarios are investigated. These alternatives include:

- o Alternate No. 1: Modification of well field operation to produce additional water to offset lost yield by using extra available well field capacity or operating affected wells with pumping water levels in well screens with additional well treatment and provisions of additional pumping energy for well operation to offset lower groundwater levels.

- o Alternative No. 2: Addition of replacement well(s) to offset lost well field capacity and provision of additional pumping energy for well operation to lower groundwater levels.

- o Alternative No. 3: Purchase of replacement water from nearby water purveyors to offset lost well field capacity and provision of additional pumping energy for well operation to offset lower groundwater levels.

Impacts to five major well fields and miscellaneous industrial and irrigation wells in the lower Kansas River Valley are summarized in various tables for present riverbed and Case 1, 2 and 3 river degradation. These impacts are expressed in terms of lost well capacity and mitigation costs for replacement of lost well capacity and additional pumping energy.

* * * * *

APPENDIX A—OBSERVATION WELL DATA

OBSERVATION WELL 11-24E-14BDA

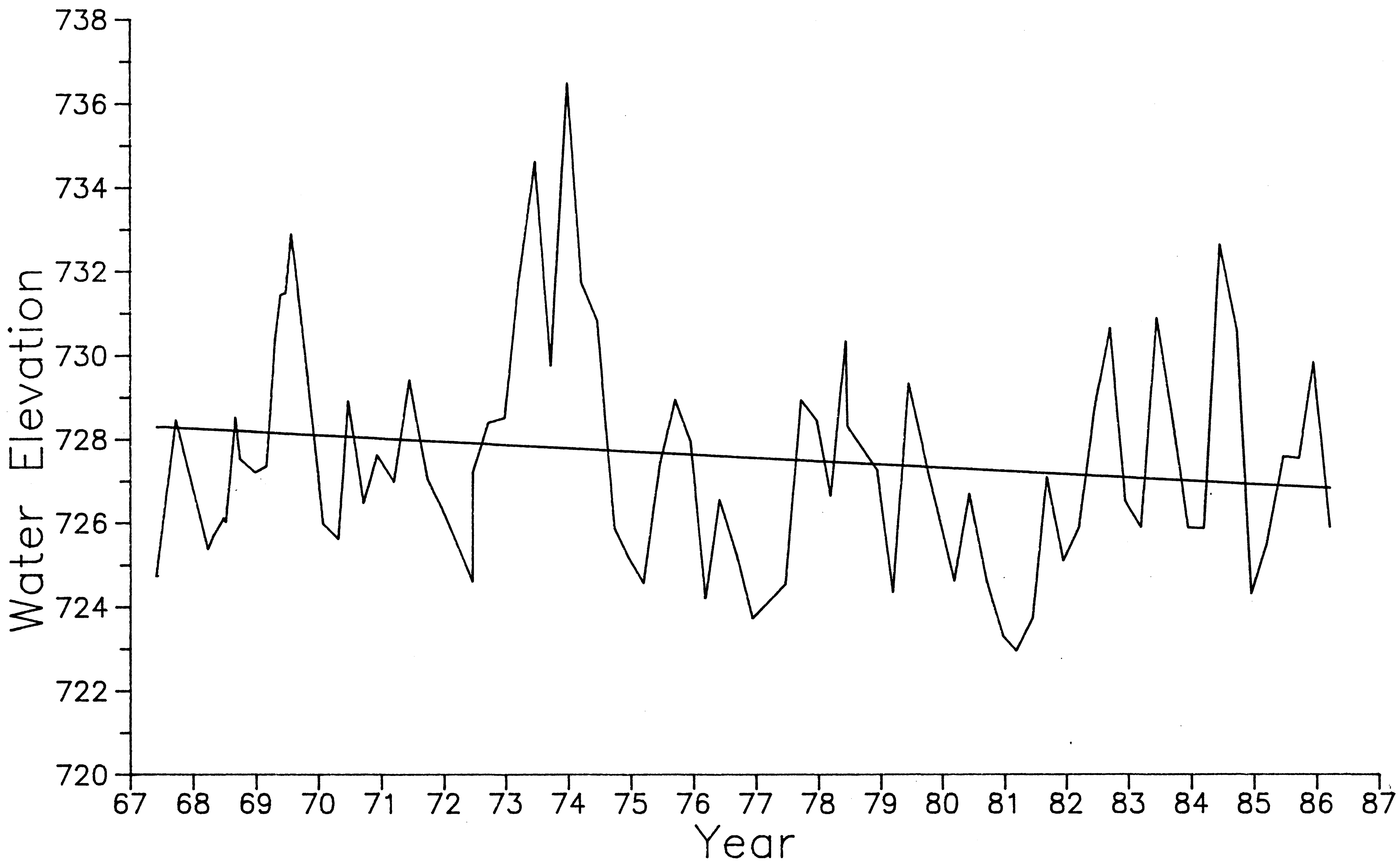

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Figure A-1
HYDROGRAPH
OBSERVATION WELL NEAR TURNER BRIDGE

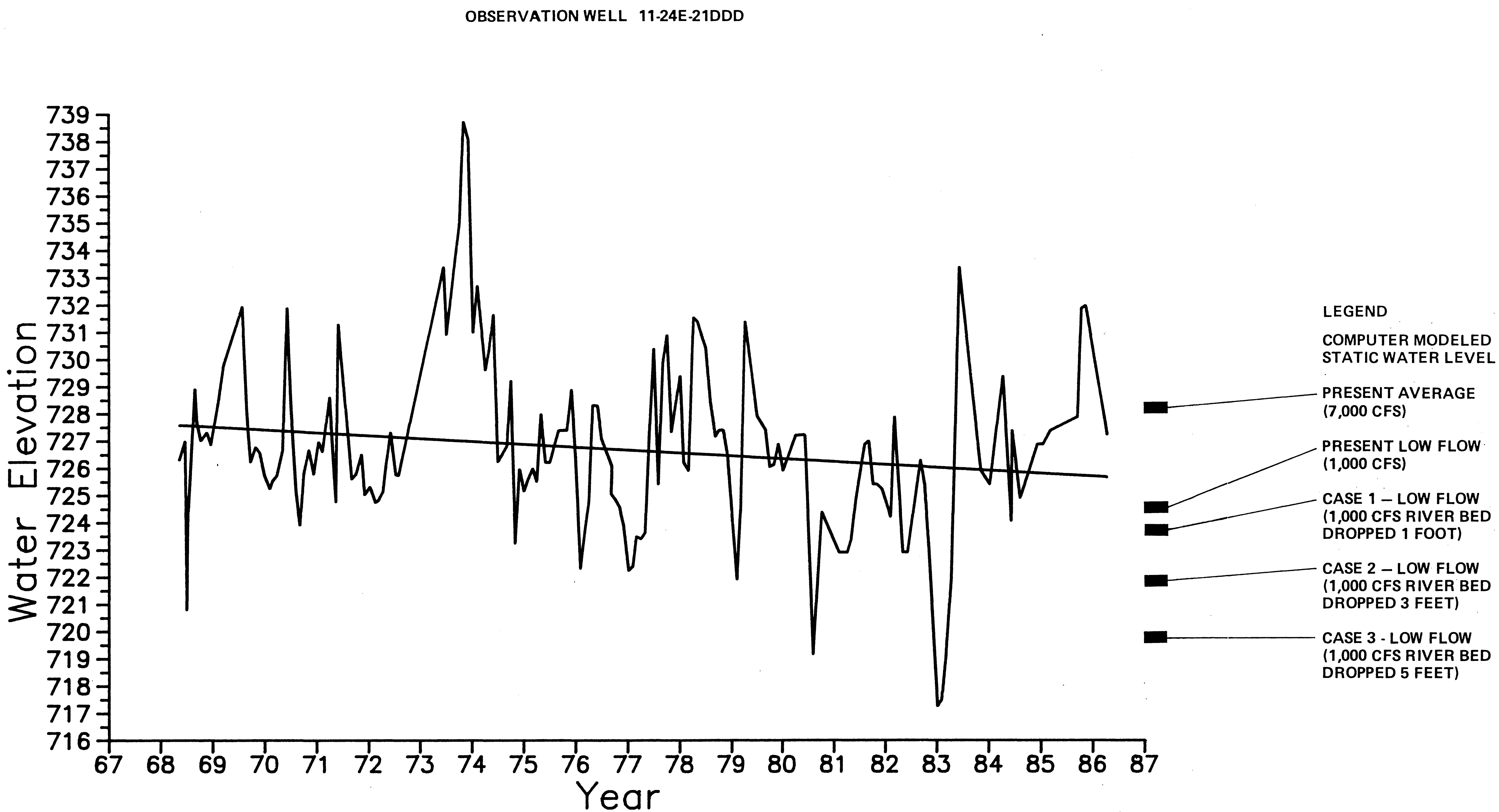

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Figure A-2
HYDROGRAPH
OBSERVATION WELL NEAR JOHNSON COUNTY WATER DISTRICT NO. 1 WELL FIELD

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

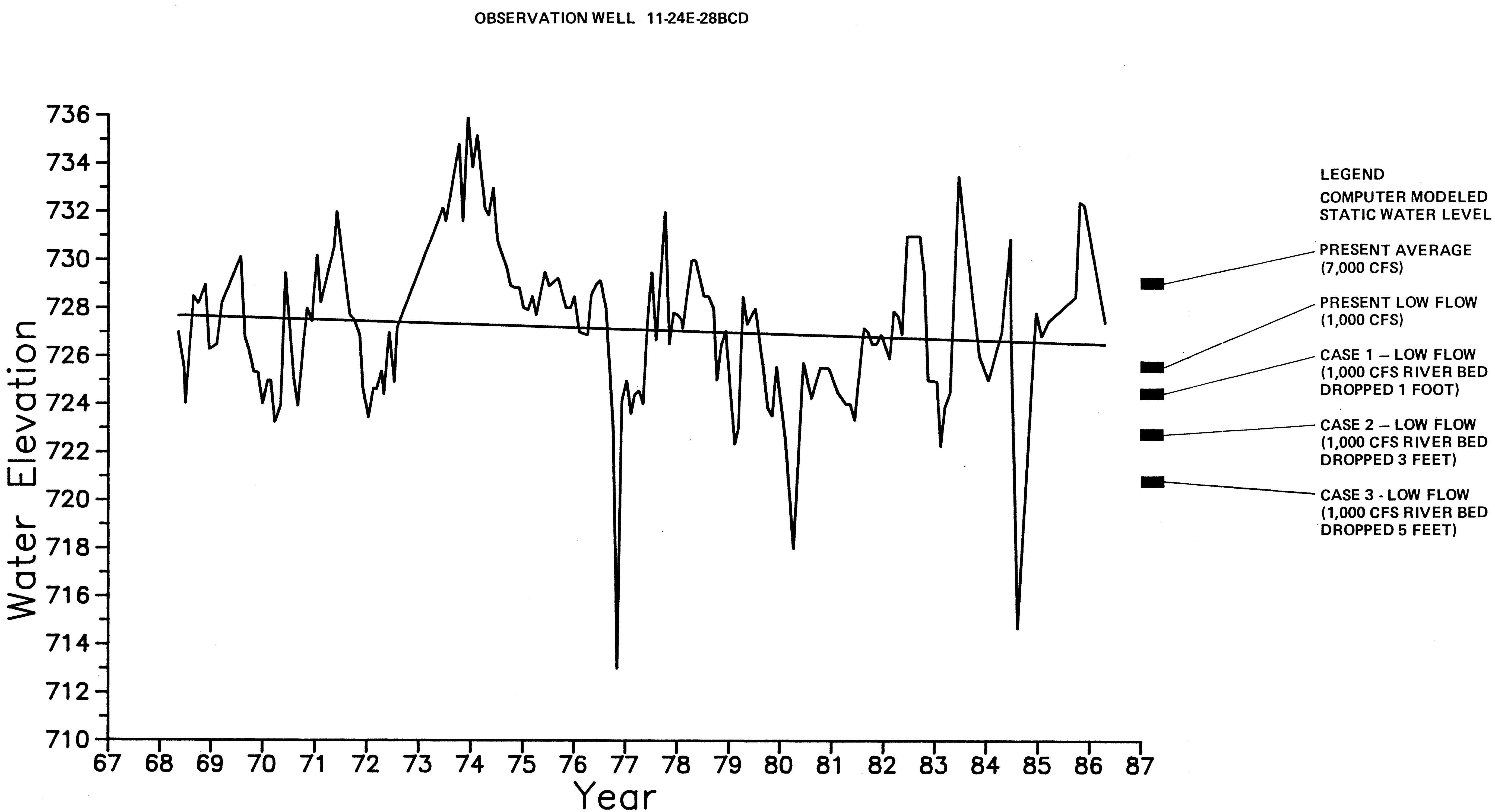

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Figure A-3
HYDROGRAPH
OBSERVATION WELL NEAR JOHNSON COUNTY WATER DISTRICT NO. 1 WELL FIELD

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

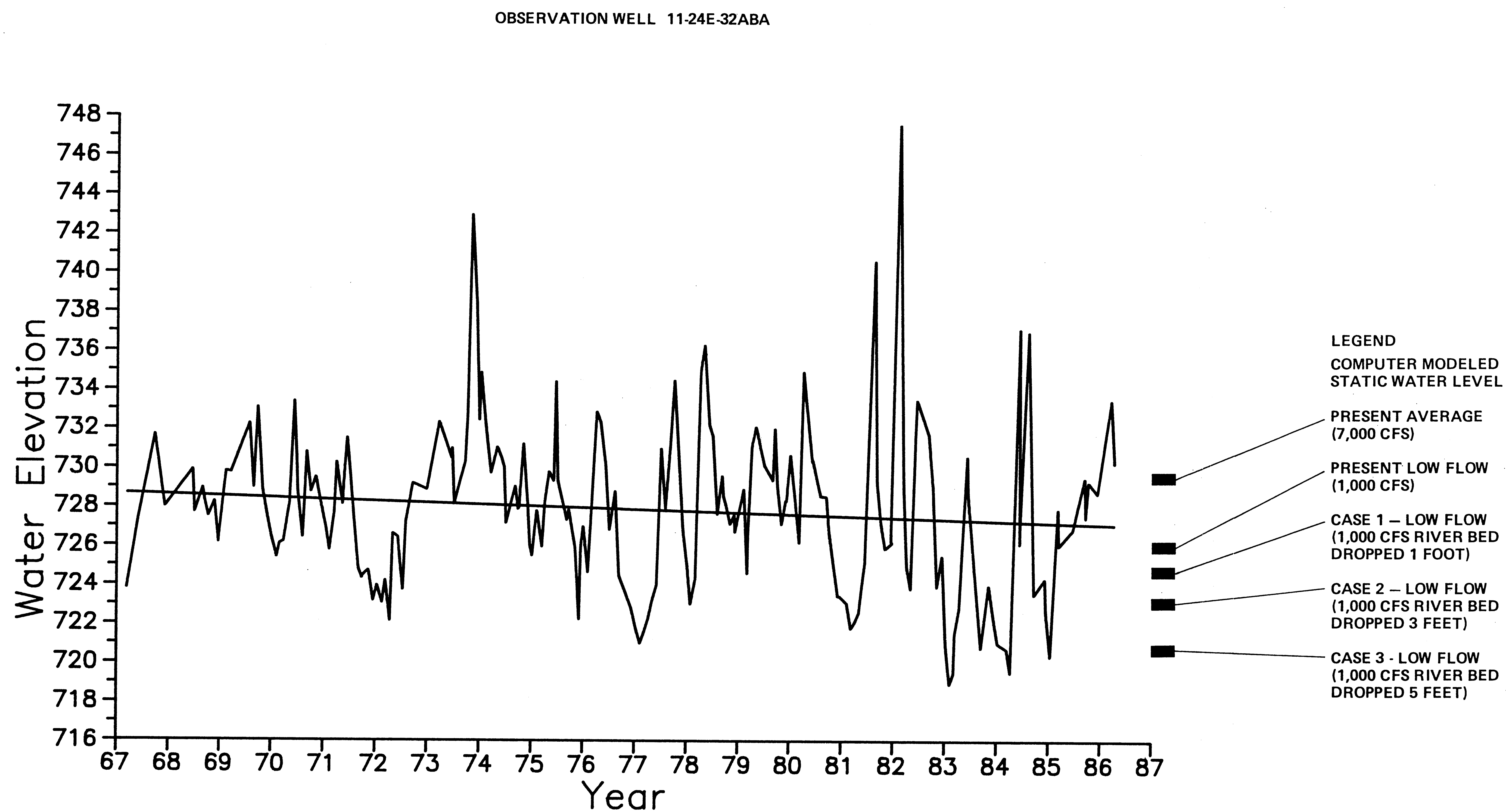

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Figure A-4
HYDROGRAPH
OBSERVATION WELL NEAR JOHNSON COUNTY WATER DISTRICT NO. 1 WELL FIELD

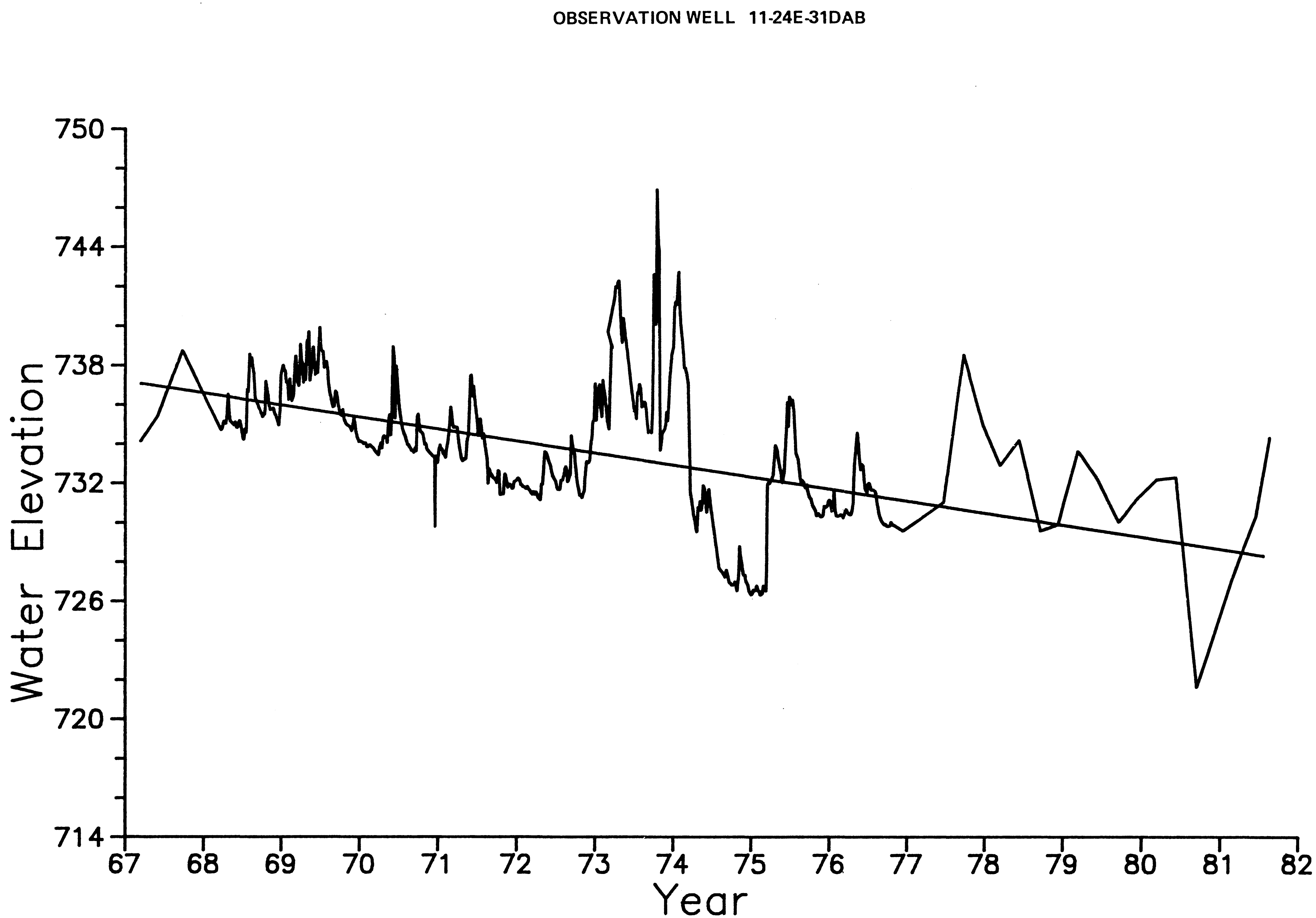

Figure A-5
HYDROGRAPH
OBSERVATION WELL NEAR
JOHNSON COUNTY WATER
DISTRICT NO. 1 WEIR

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USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

OBSERVATION WELL 12-22E-25BCCB

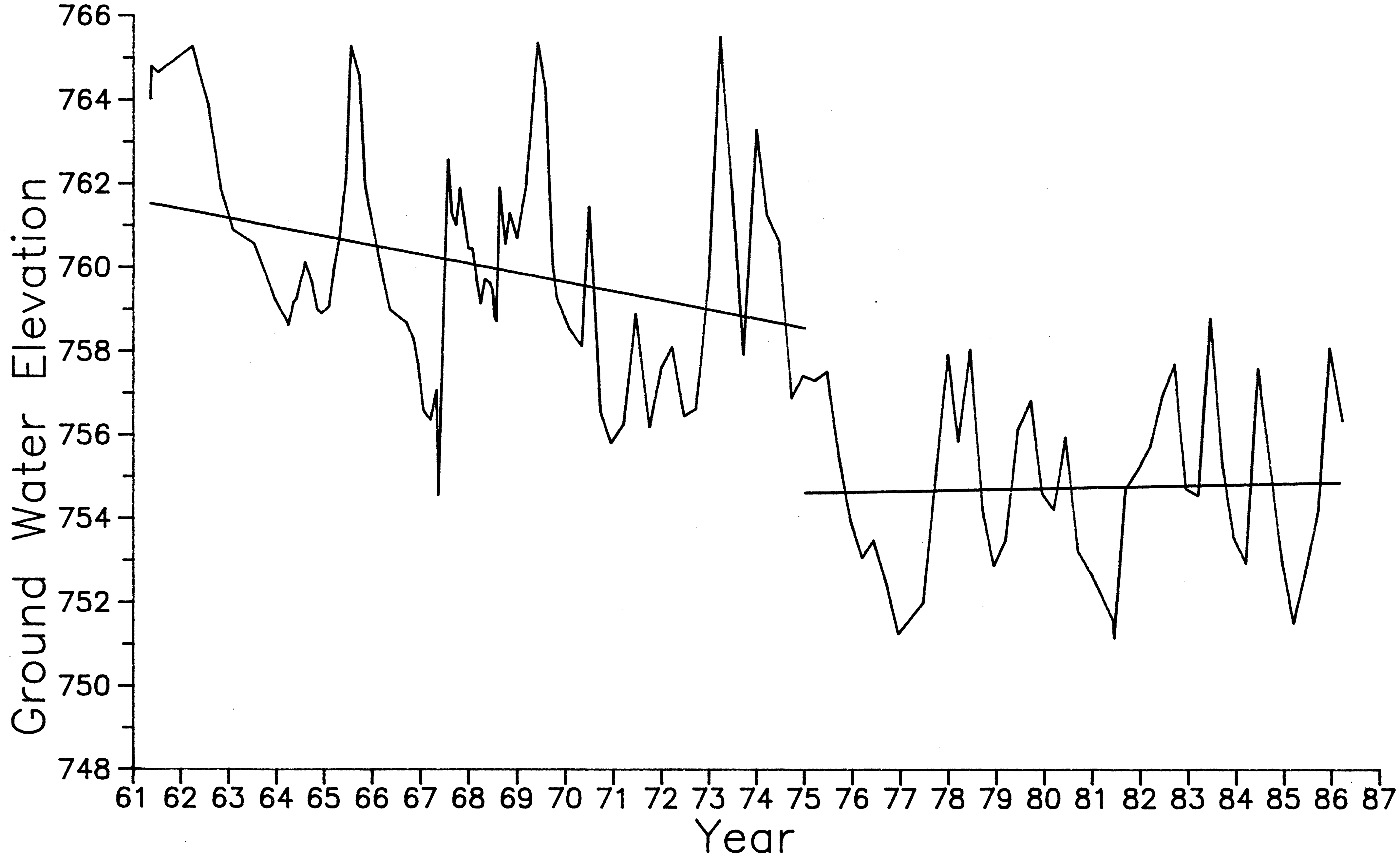

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Figure A-6
HYDROGRAPH
OBSERVATION WELL NEAR
OLATHE WELL FIELD

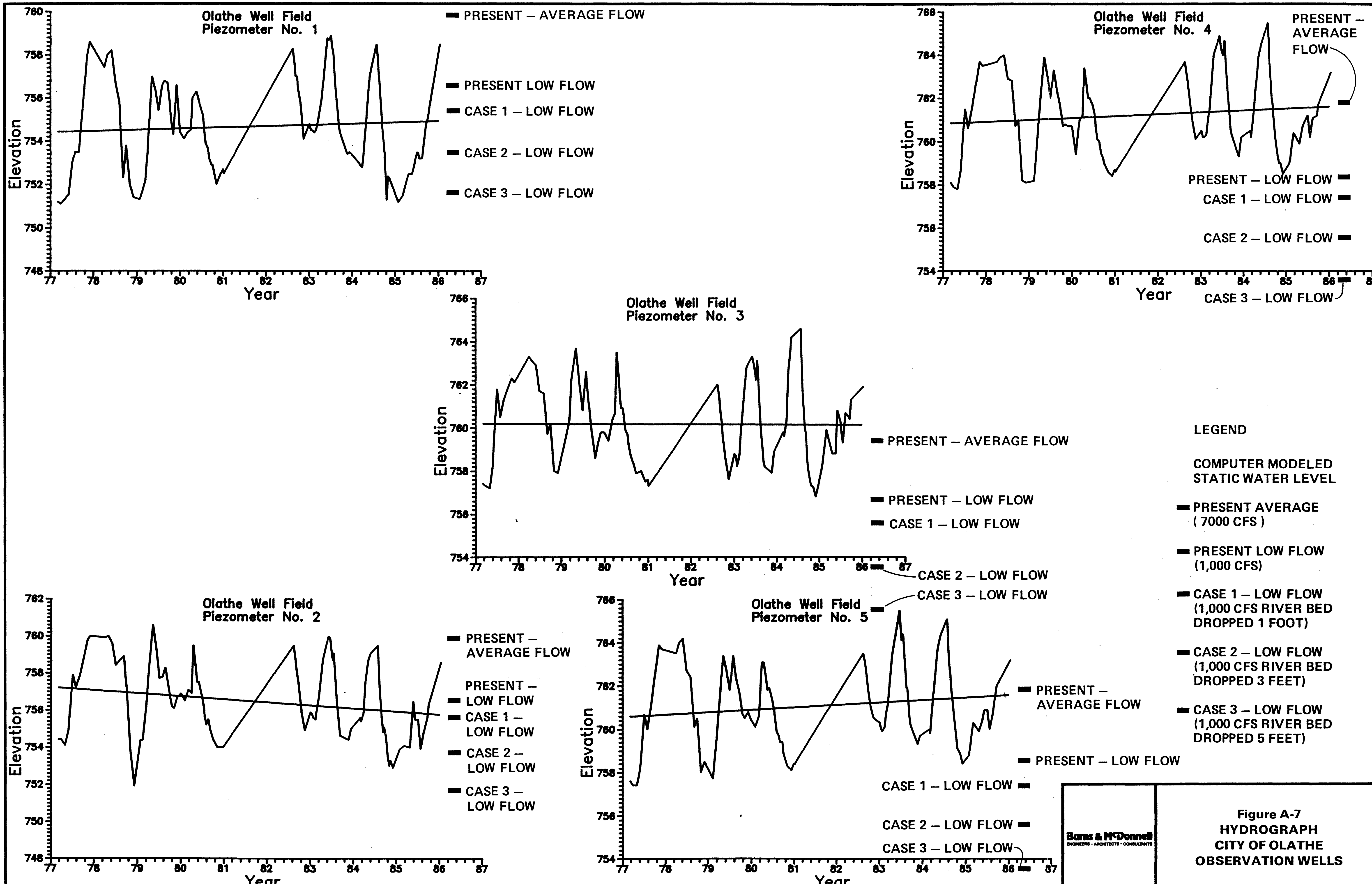

Figure A-7
HYDROGRAPH
CITY OF OLATHE
OBSERVATION WELLS

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

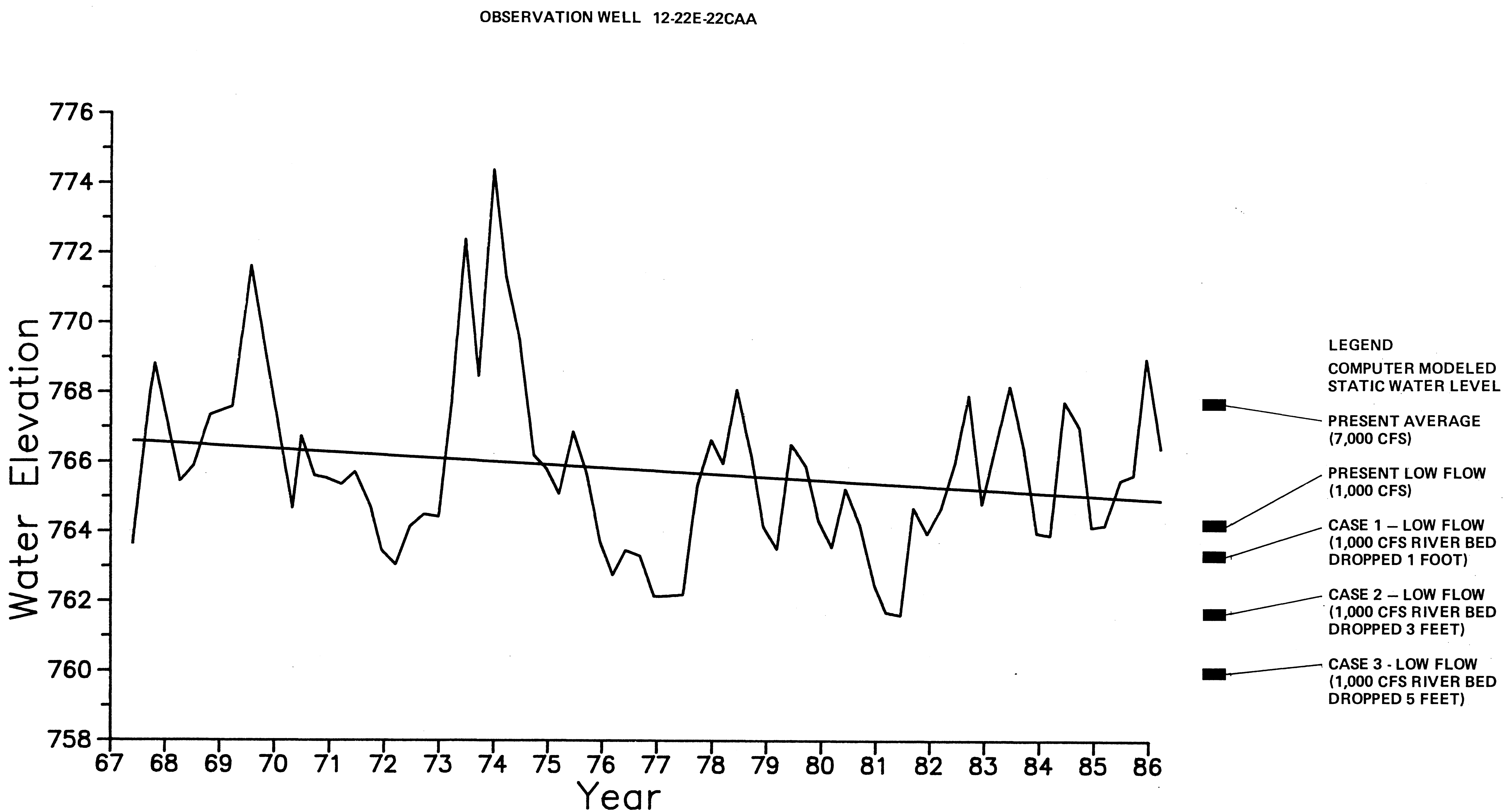

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Figure A-8
HYDROGRAPH
OBSERVATION WELL NEAR SUNFLOWER ARMY ORDNANCE PLANT NORTH WELL FIELD

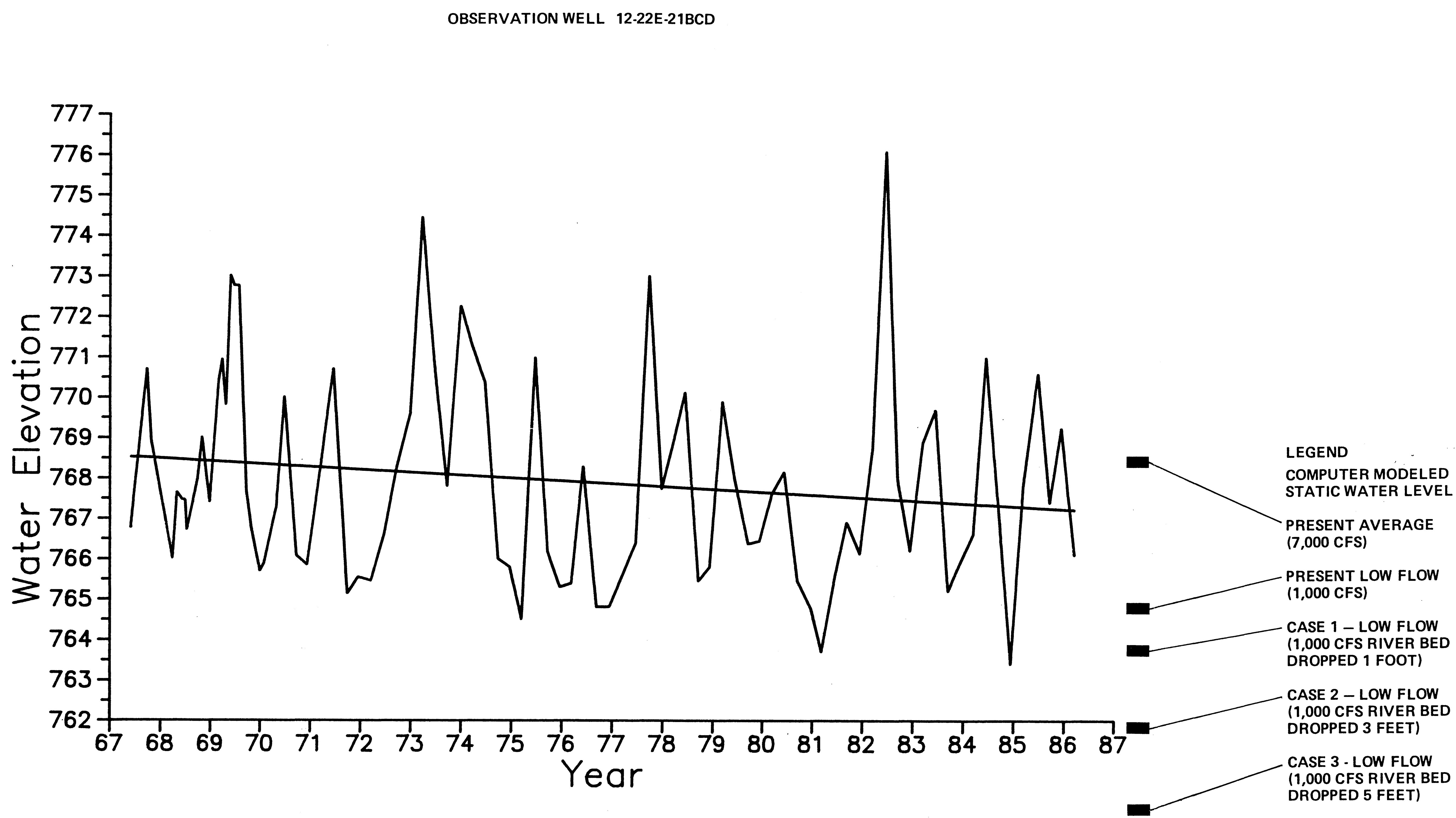

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Figure A-9
HYDROGRAPH
OBSERVATION WELL NEAR SUNFLOWER ARMY ORDNANCE PLANT NORTH WELL FIELD

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

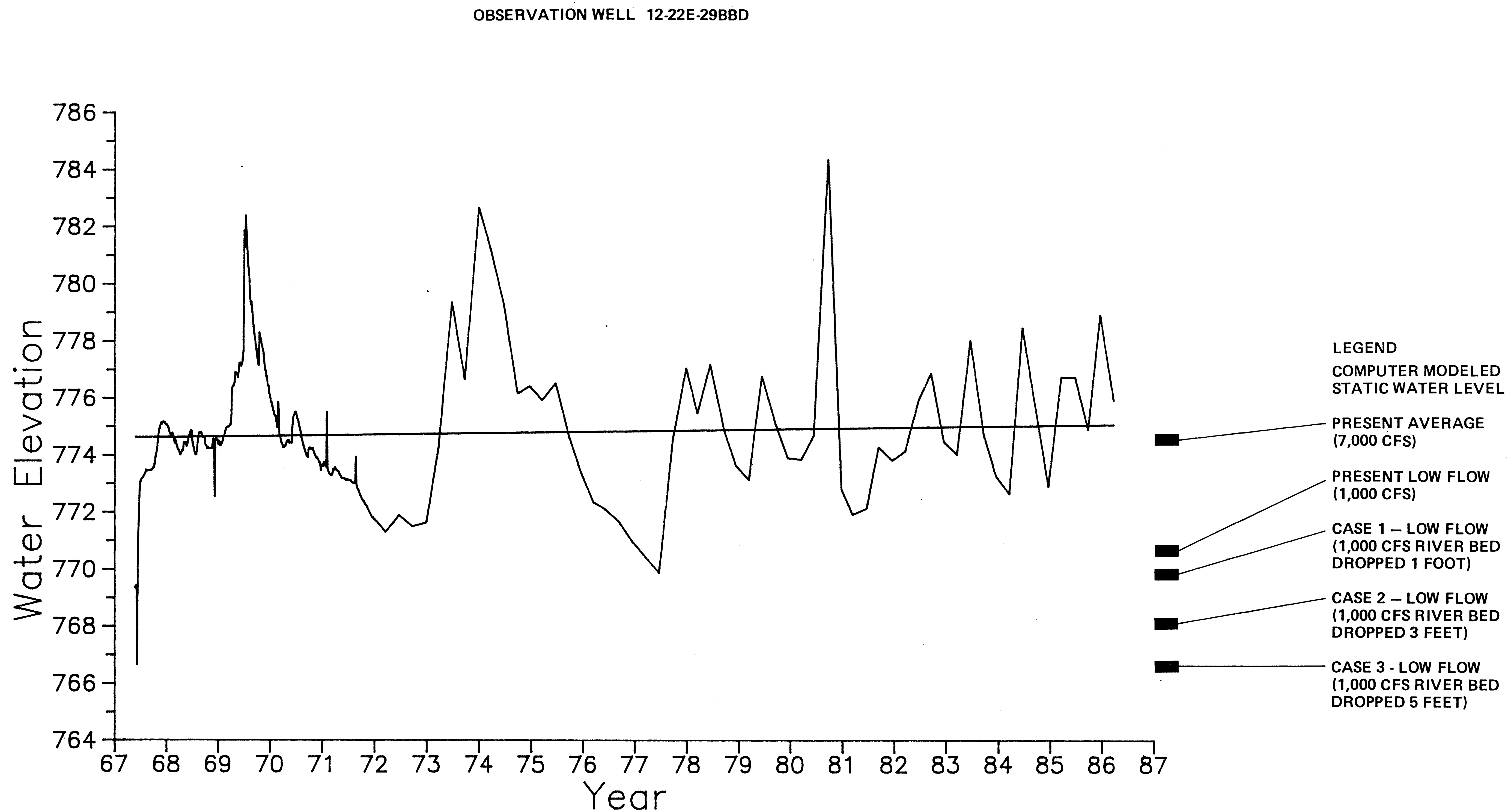

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Figure A-10
HYDROGRAPH
OBSERVATION WELL NEAR SUNFLOWER ARMY ORDNANCE PLANT SOUTH WELL FIELD

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

APPENDIX B—MODEL DATA

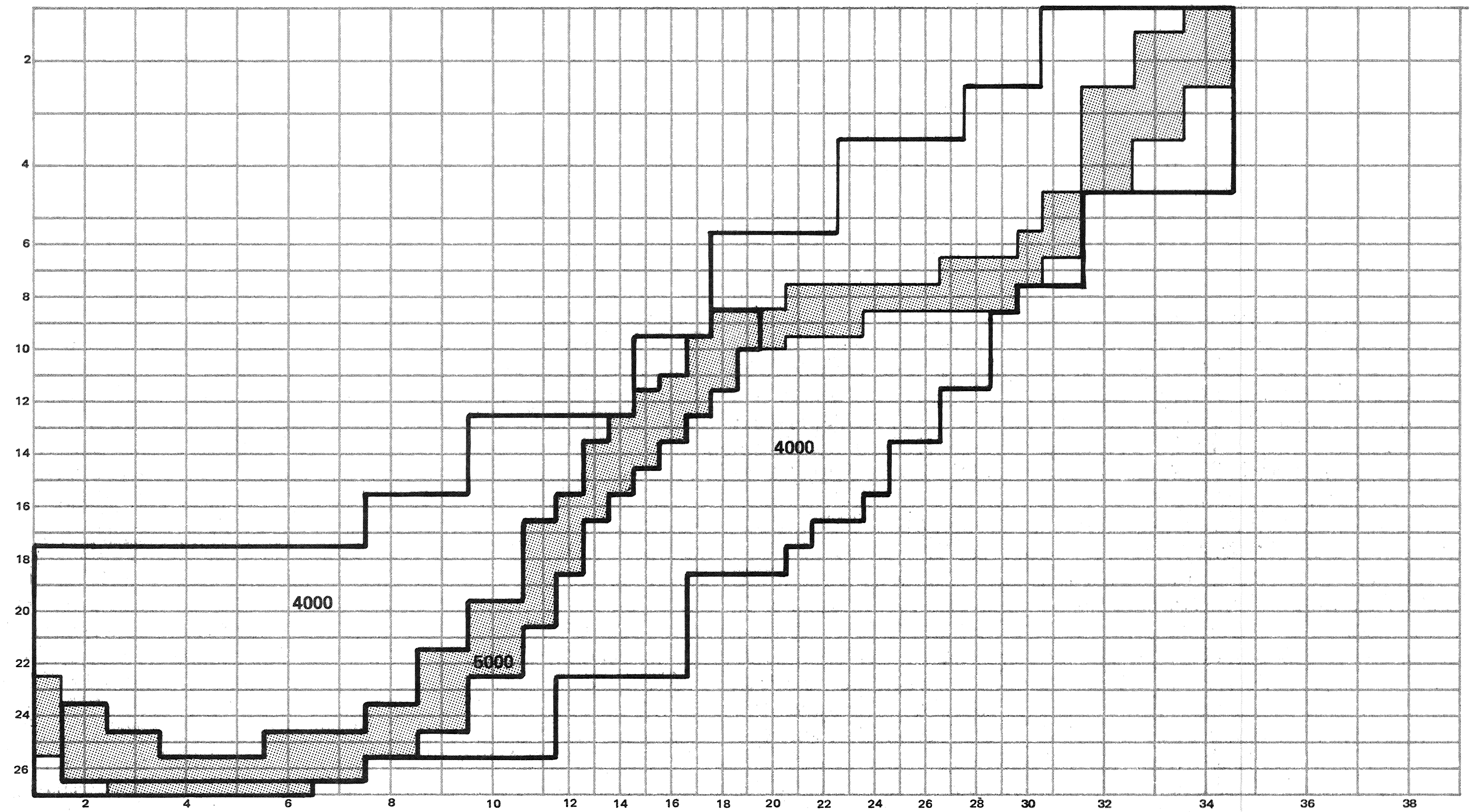

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Figure B-1
AREA 1
PERMEABILITY DISTRIBUTION

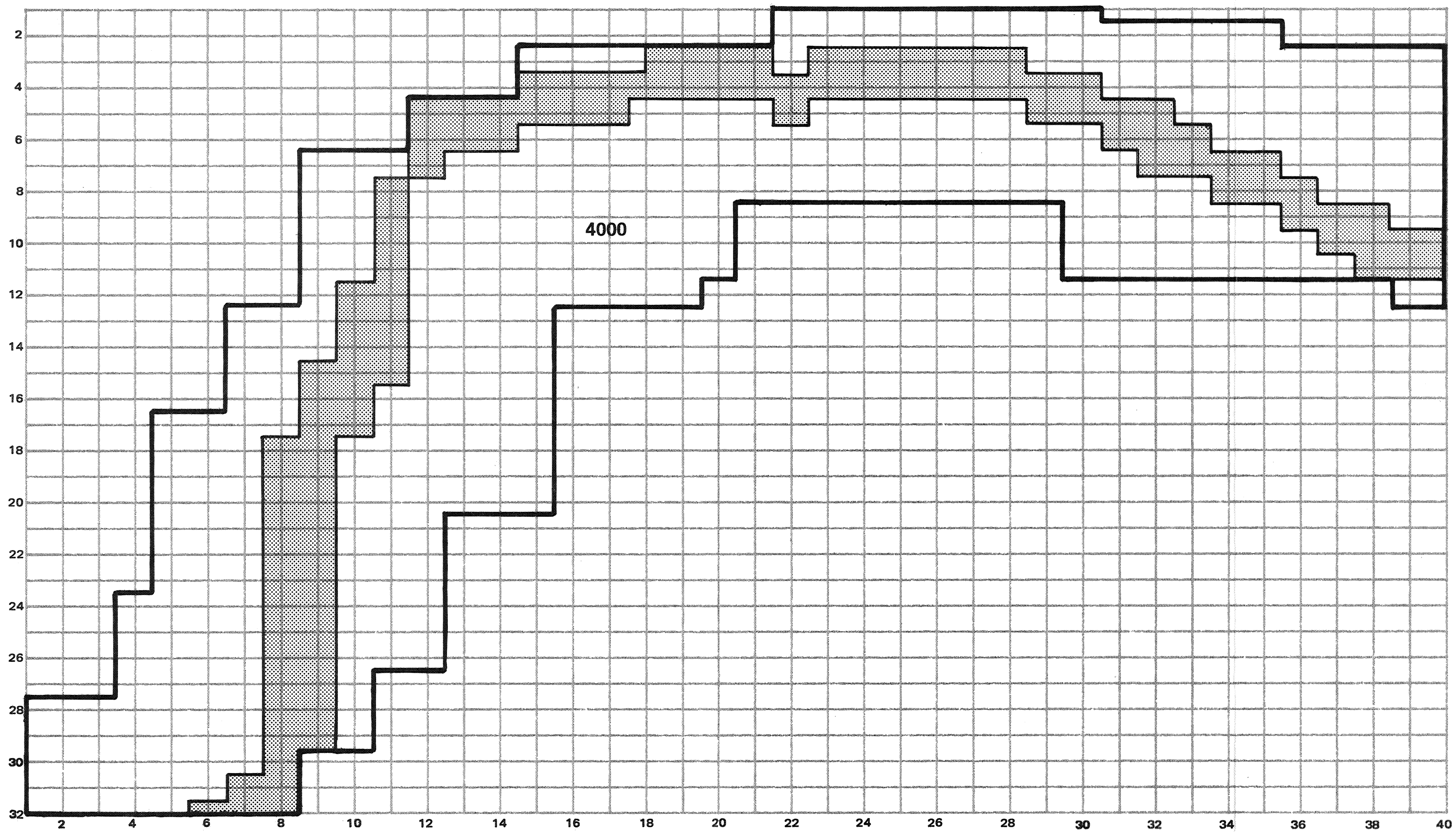

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Figure B-2
AREA-2
PERMEABILITY DISTRIBUTION

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

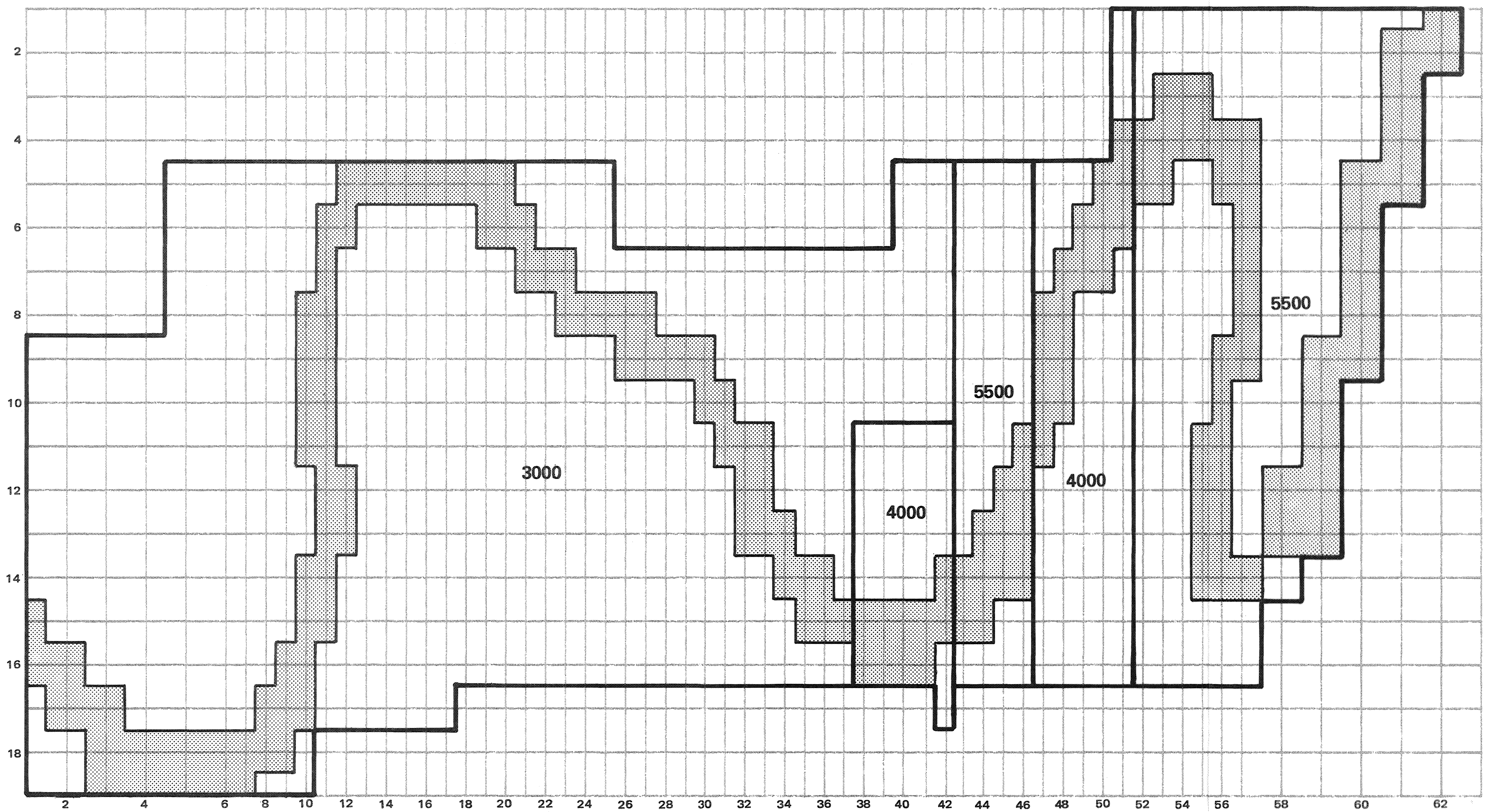

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Figure B-3
AREA 3
PERMEABILITY DISTRIBUTION

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

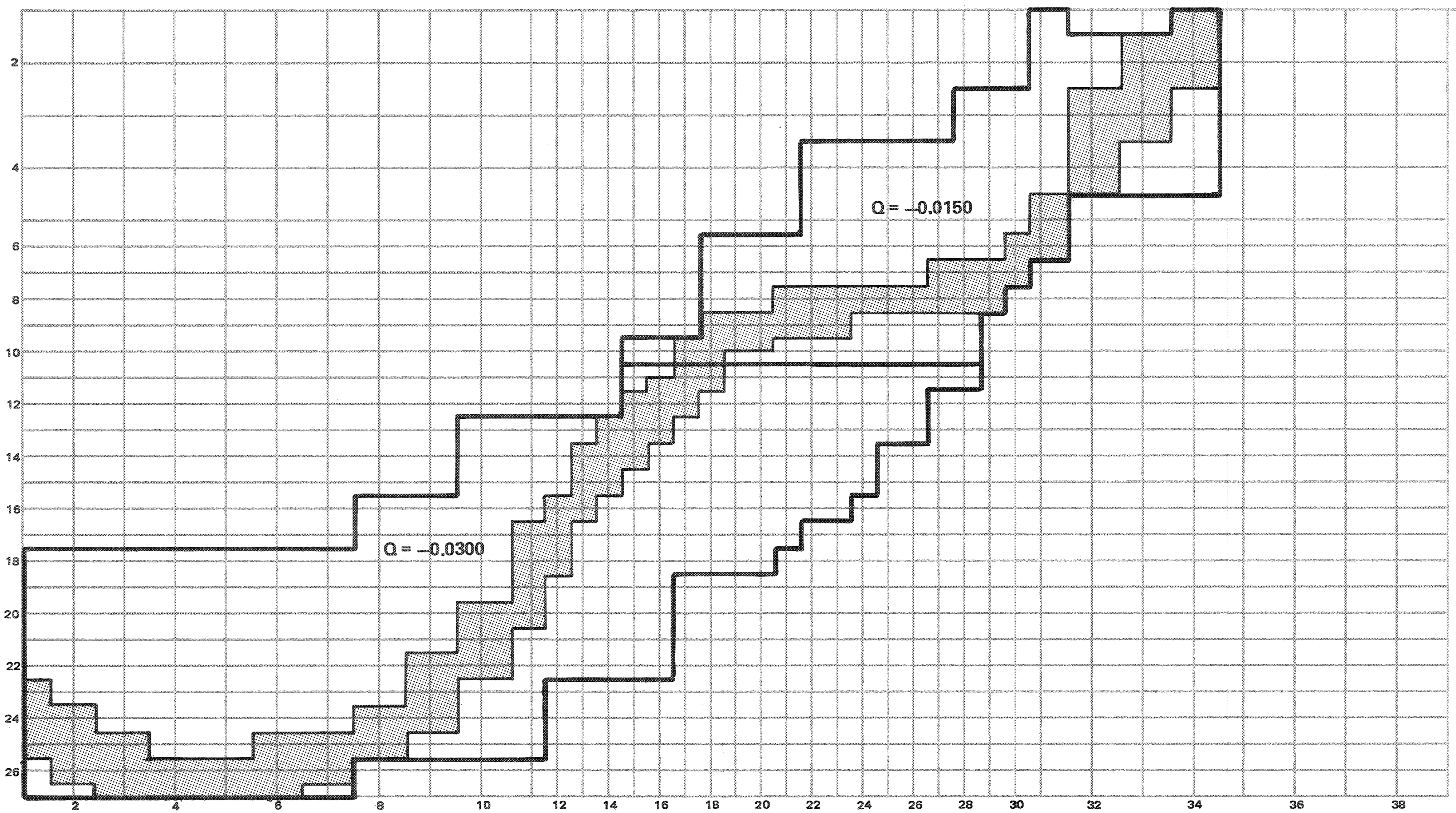

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Figure B-4
AREA 1
GROUNDWATER
RECHARGE DISTRIBUTION

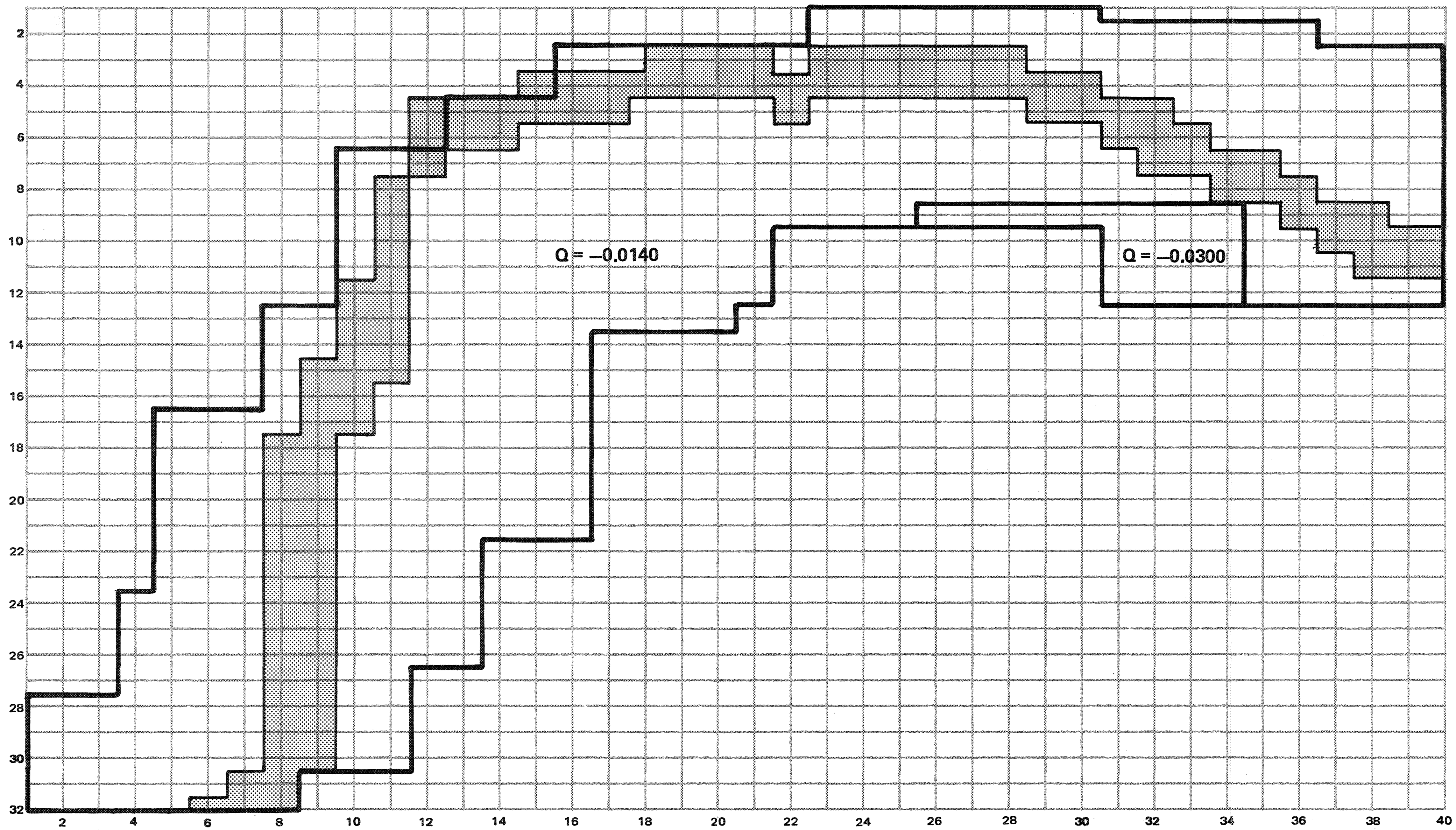

Figure B-5
AREA 2
GROUNDWATER
RECHARGE DISTRIBUTION

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USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

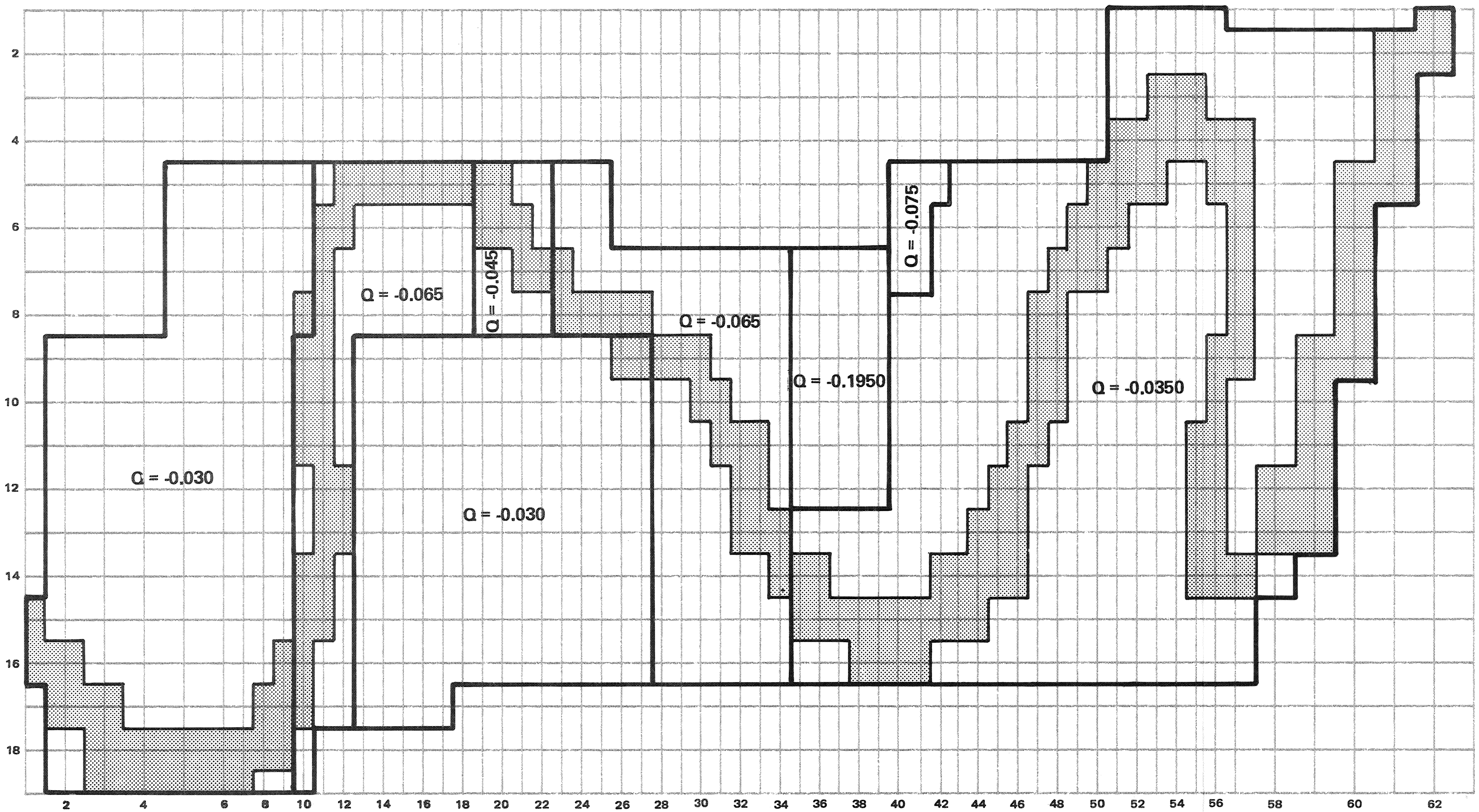

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Figure B-6
AREA 3
GROUNDWATER
RECHARGE DISTRIBUTION

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-4	-5	-6	-6	-5	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-5	-6	-7	-7	-5	0	0	0	0
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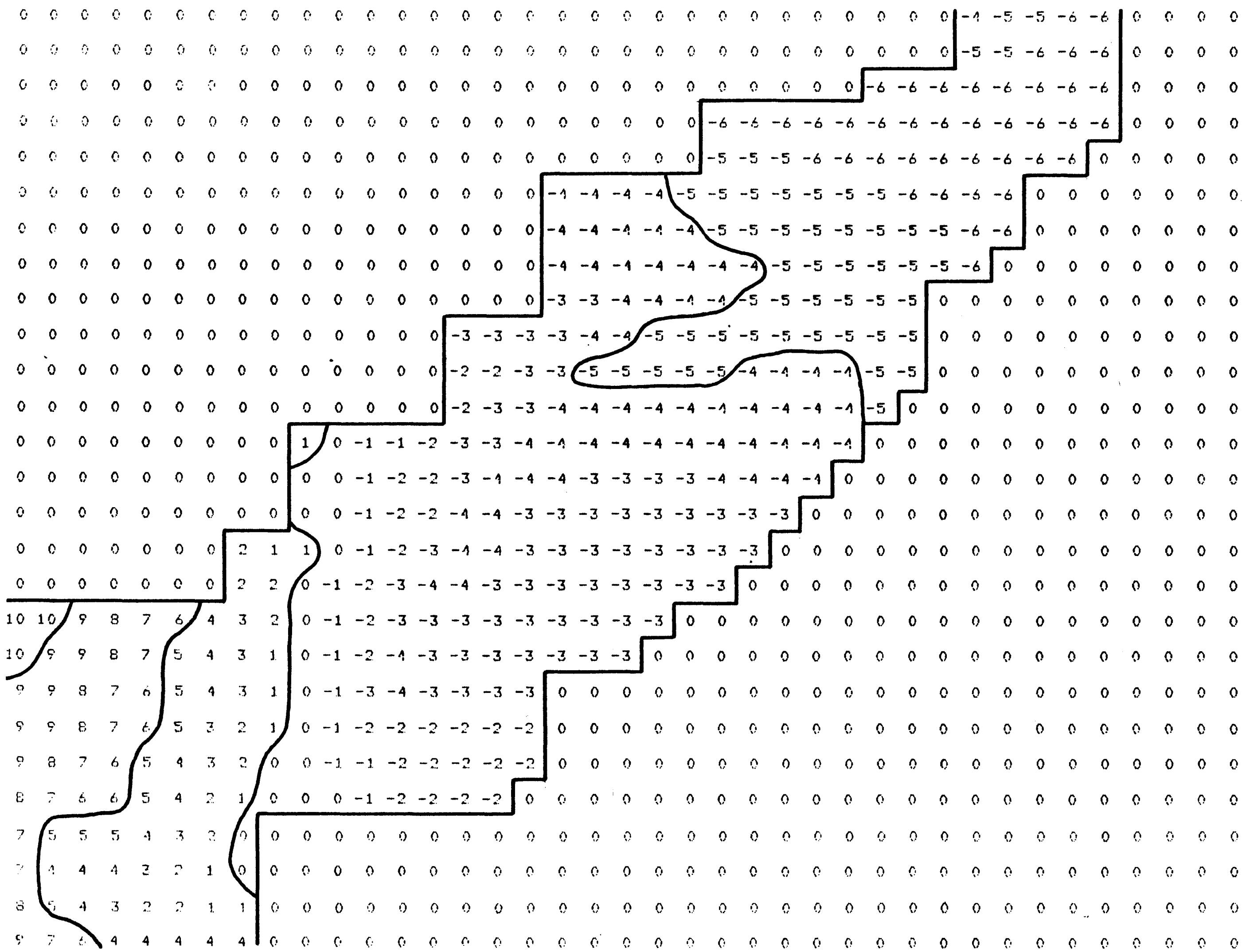
Figure B-7

MODEL AREA 1
CHECK FILE BASED ON
FADER 1967 GROUNDWATER MAP



MEAN DIFFERENCE IN HEADS = 0.16 FEET

STANDARD DEVIATION = 0.85 FEET

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Figure B-8

MODEL AREA 1
CALIBRATED COMPUTER FILE

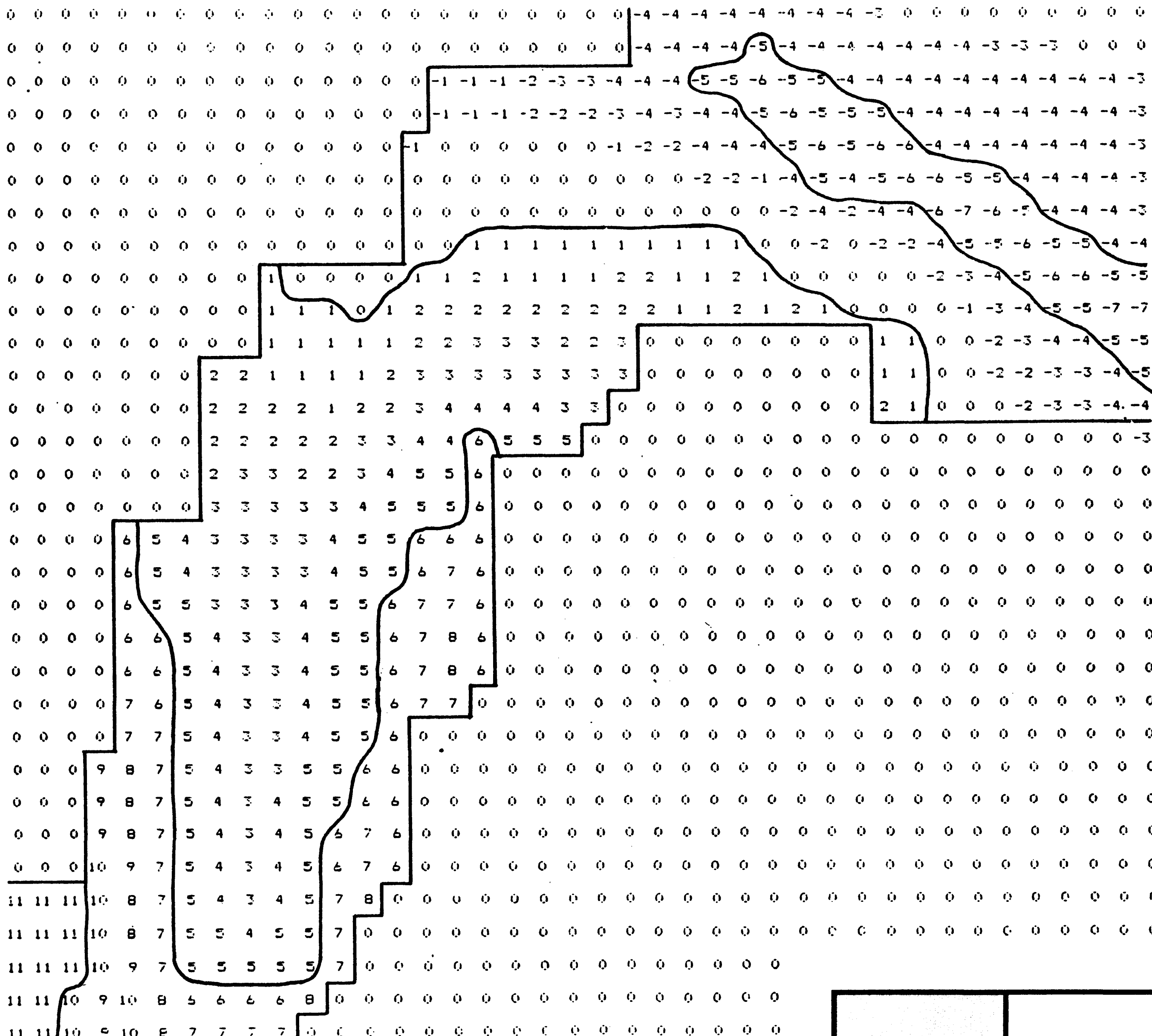

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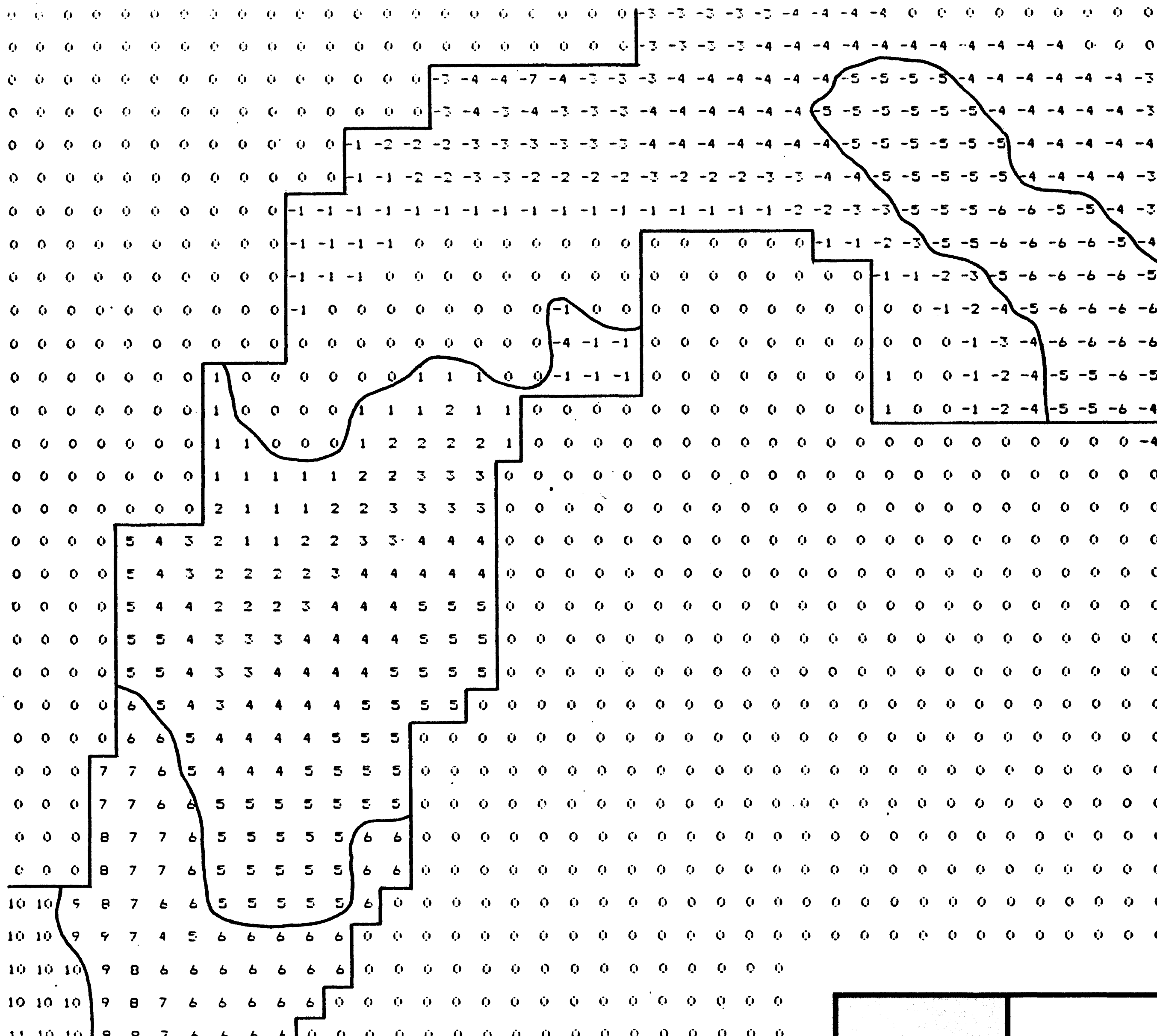
Figure B-9

MODEL AREA 2
CHECK FILE BASED ON
FADER 1967 WATER LEVEL MAP



MEAN DIFFERENCE IN HEADS = 0.15 FEET

STANDARD DEVIATION = 0.81 FEET

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Figure B-10
MODEL AREA 2
CALIBRATED COMPUTER MODEL

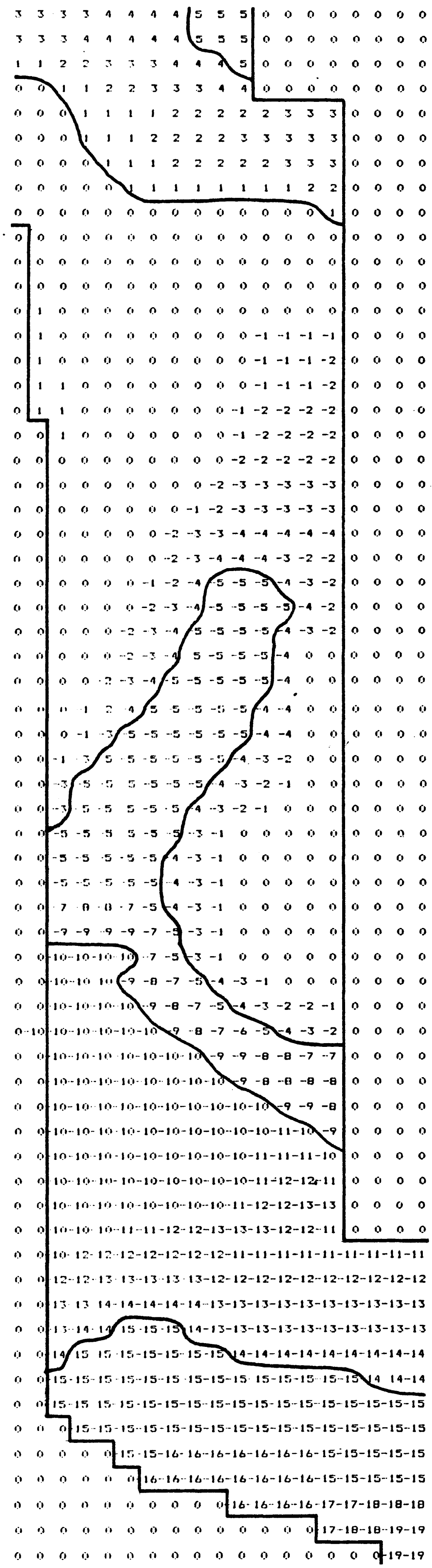

Figure B-11
MODEL AREA 3
CHECK FILE BASED ON
FADER 1967 WATER LEVEL MAP

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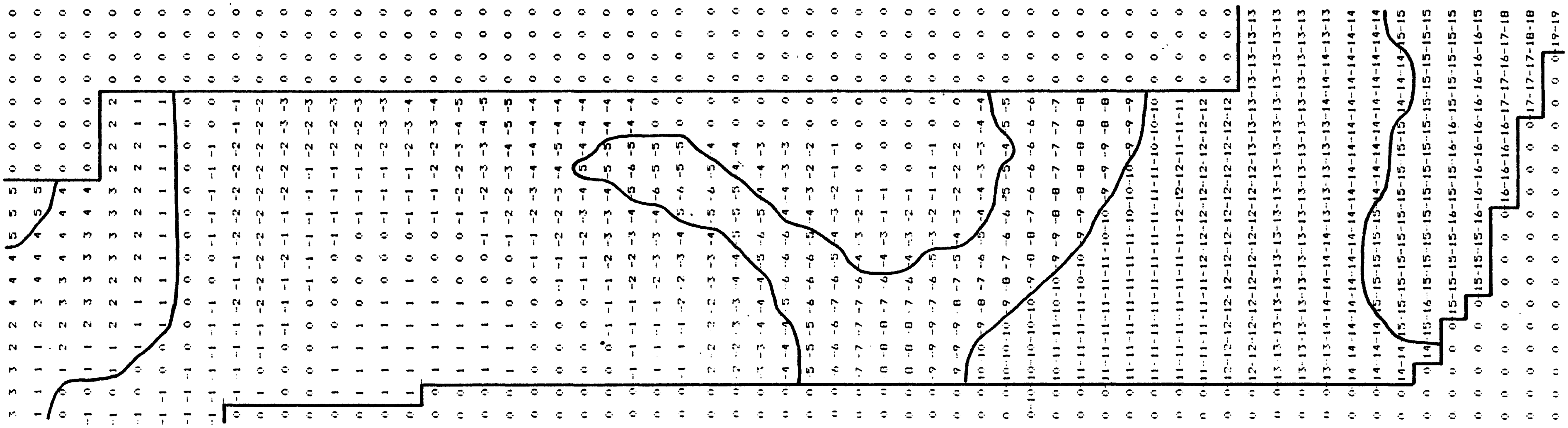

MEAN DIFFERENCE IN HEADS = 0.2 FEET
STANDARD DEVIATION = 0.91 FEET

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Figure B-12
CALIBRATED COMPUTER MODEL

APPENDIX C—RIVER AND GROUNDWATER PROFILES FOR CASES 1,2, & 3

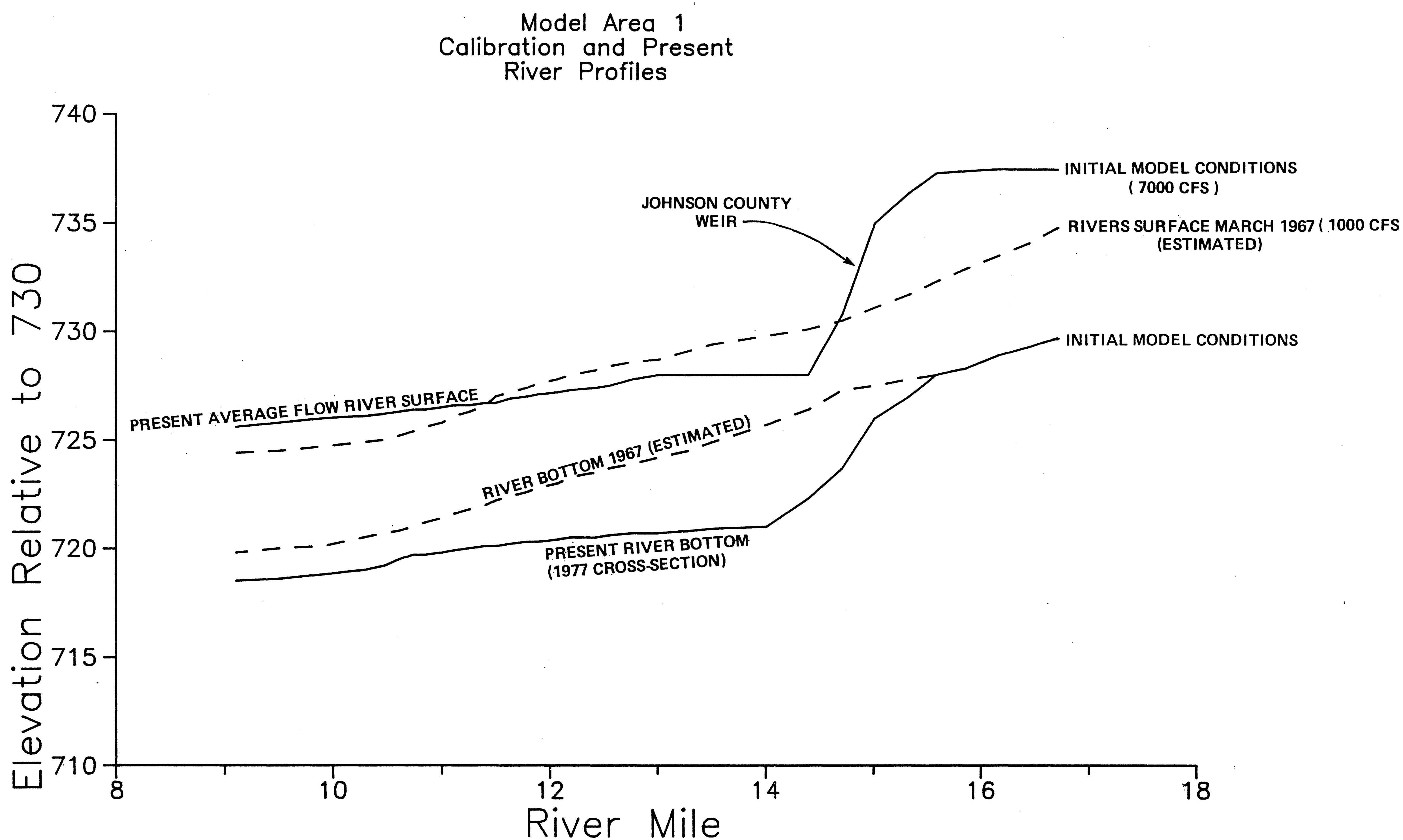

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Figure C-1
CALIBRATION AND PRESENT RIVER PROFILE

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

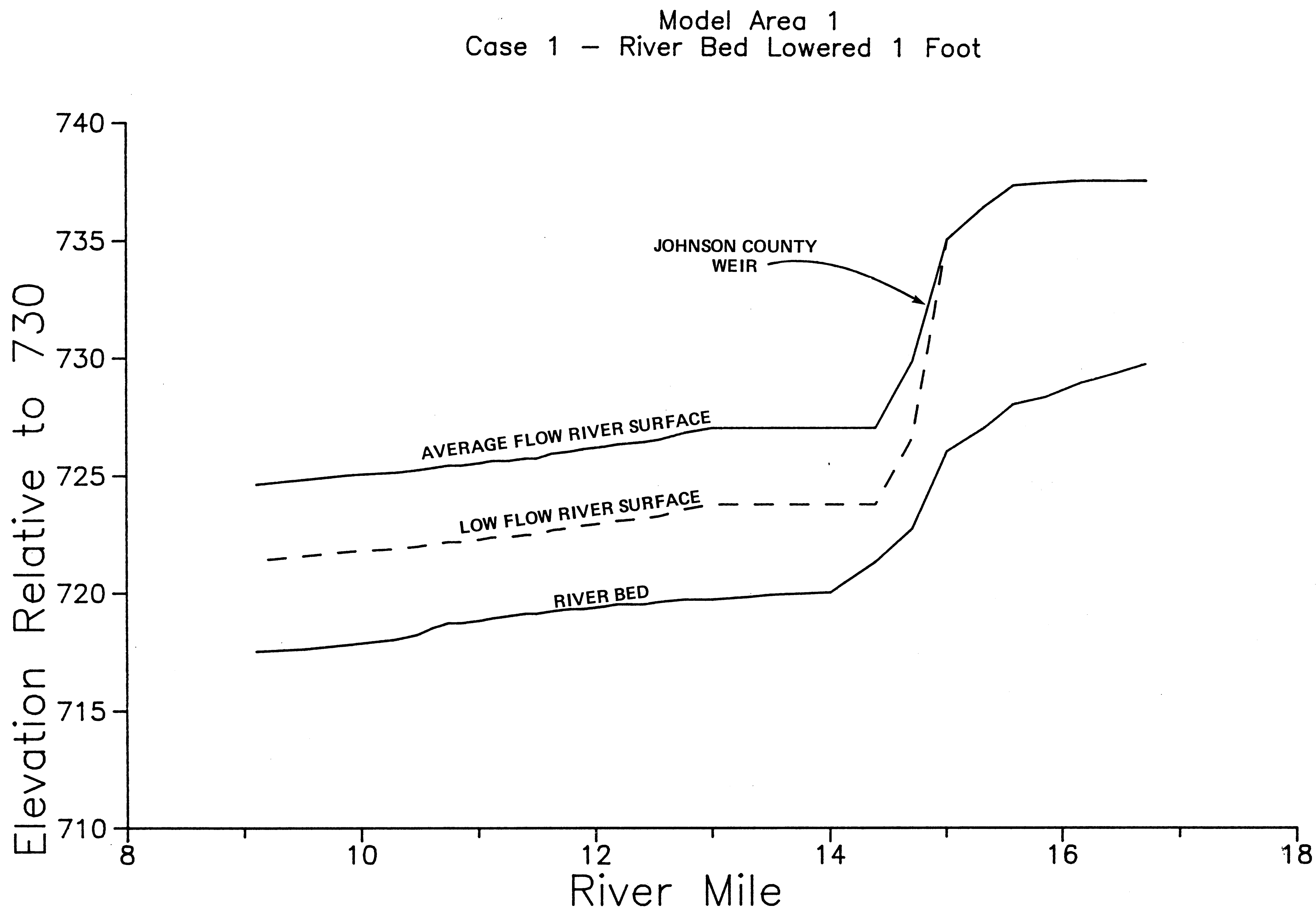

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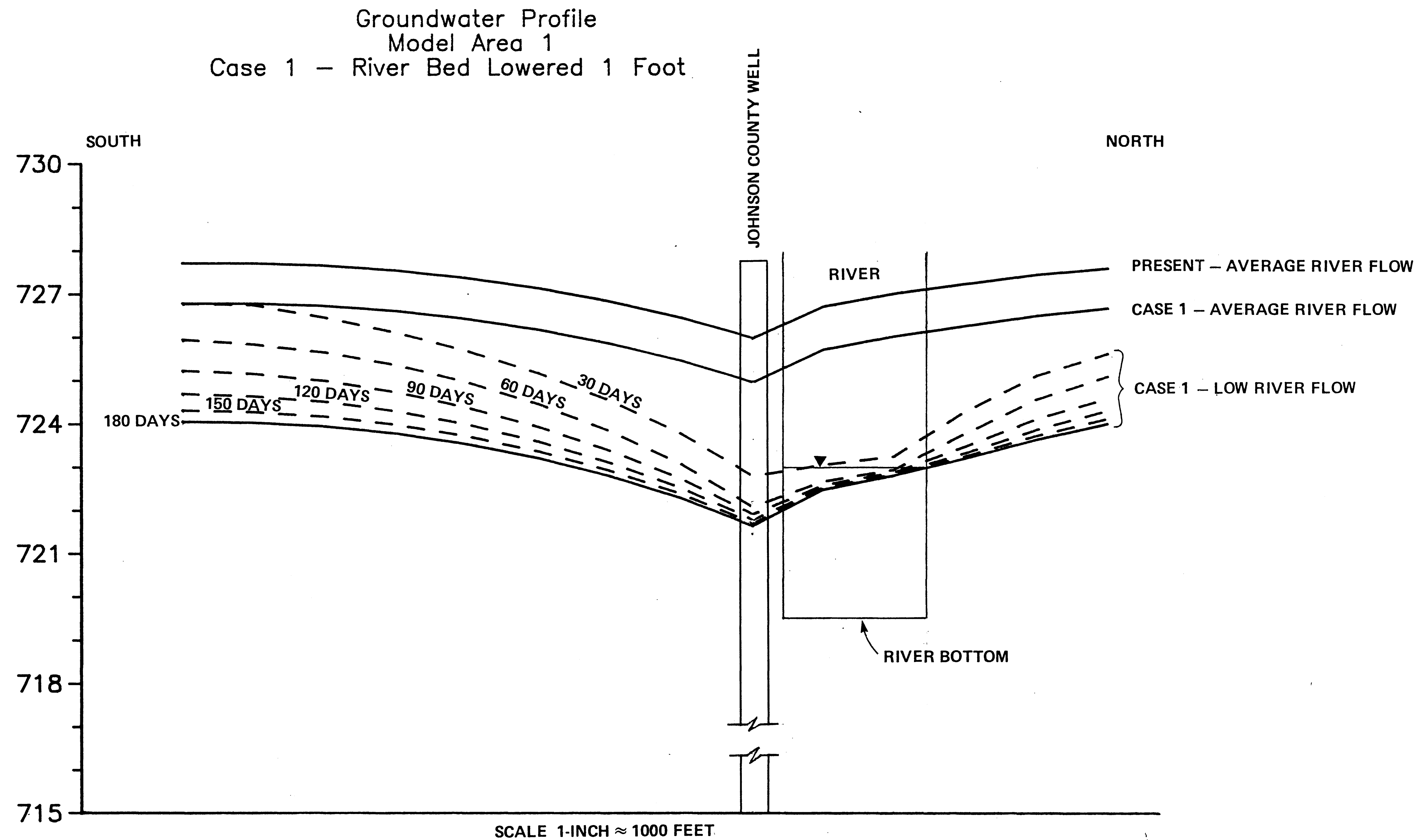
Figure C-2
RIVER PROFILE
CASE 1

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-3
GROUNDWATER PROFILE
CASE 1

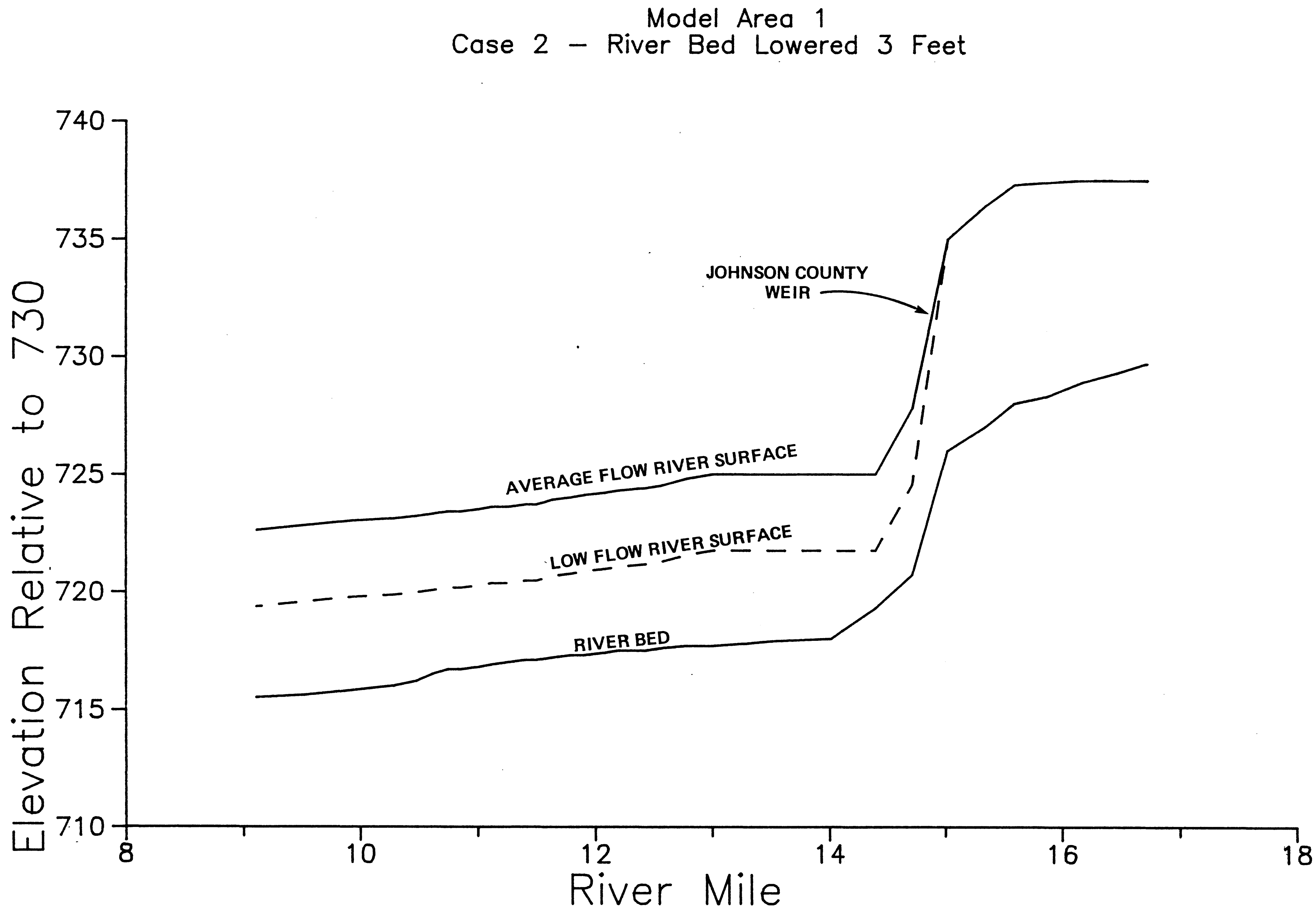

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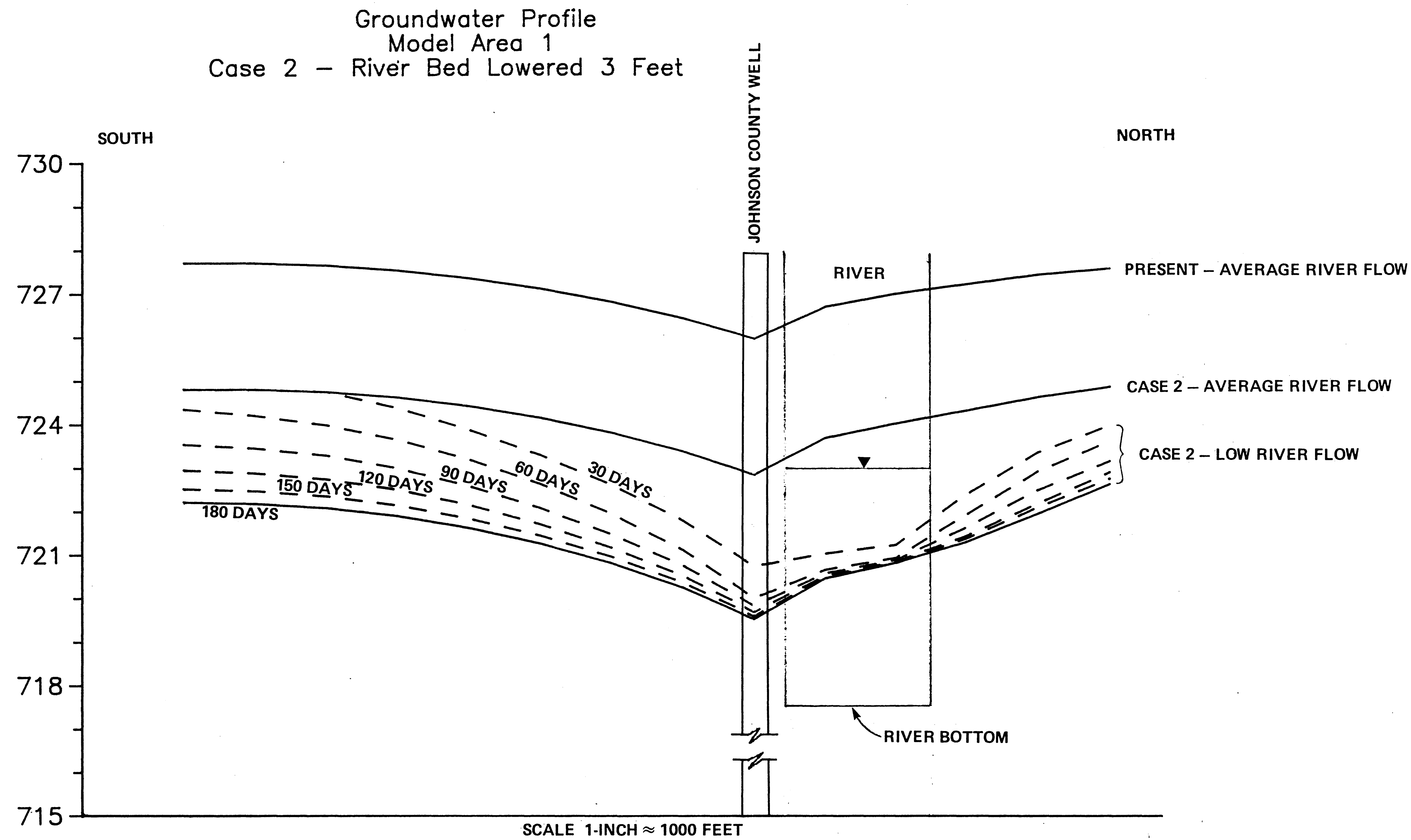
Figure C-4
RIVER PROFILE
CASE 2

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-5
GROUNDWATER PROFILE
CASE 2

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

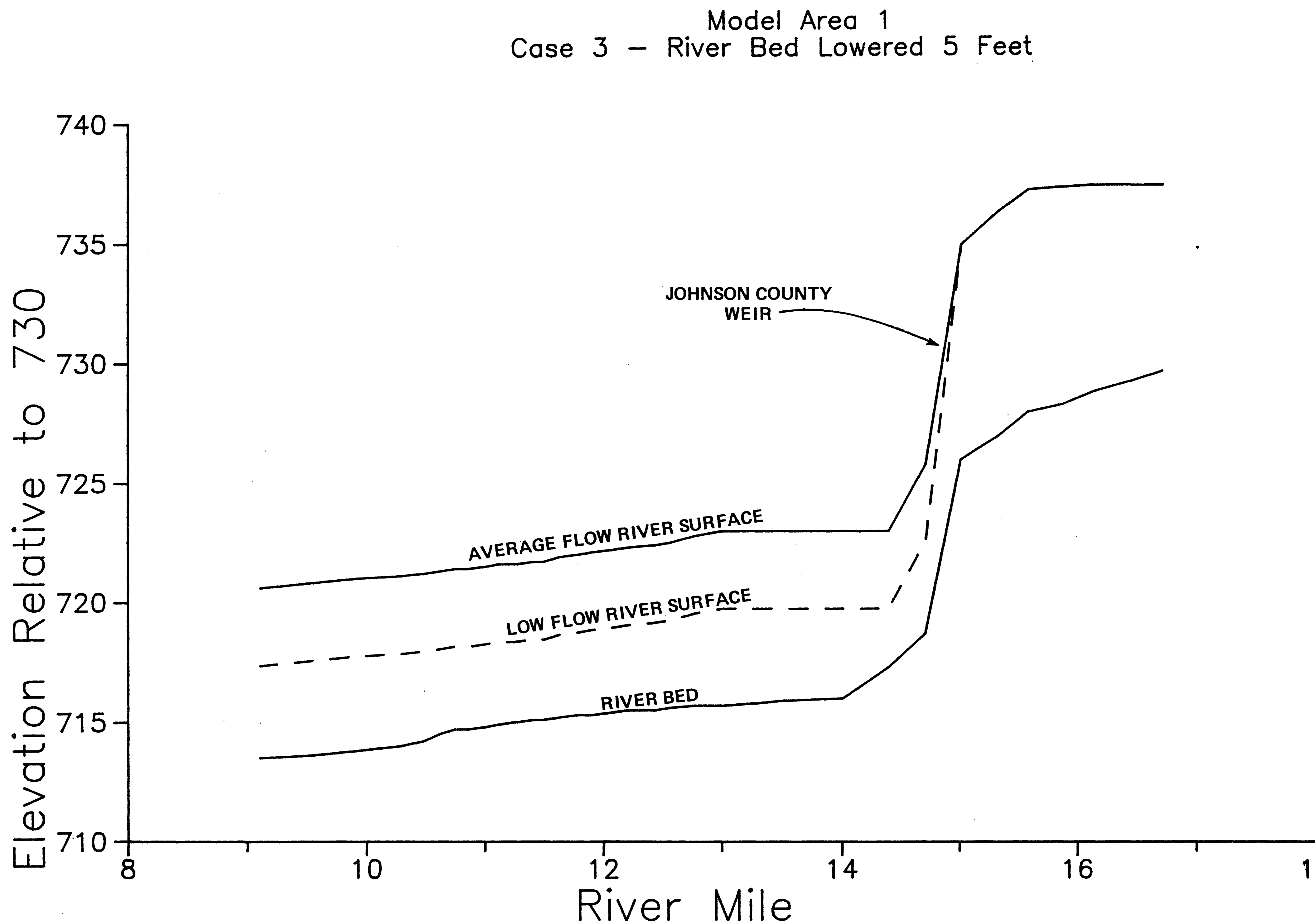

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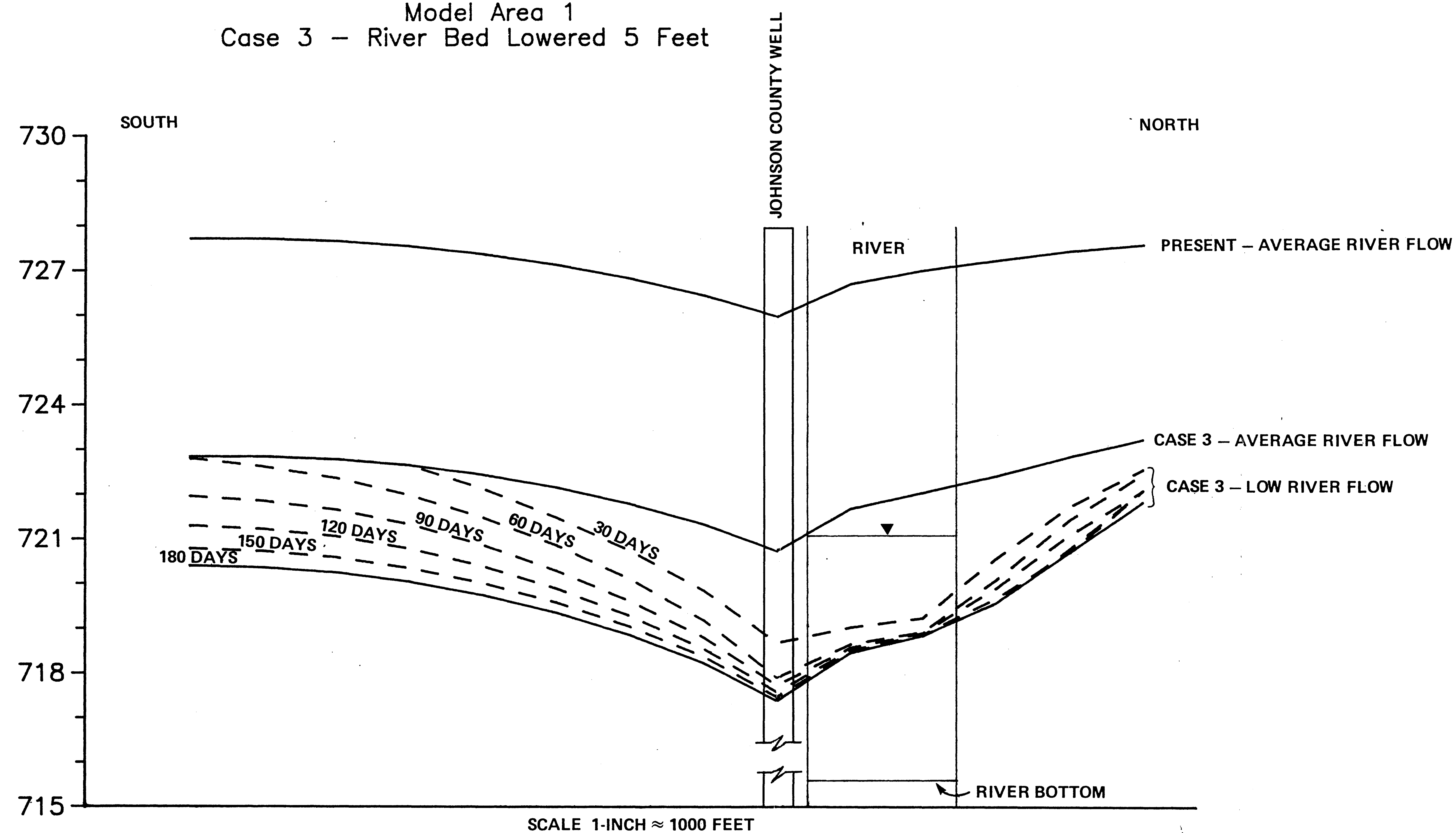
Figure C-6
RIVER PROFILE
CASE 3

Groundwater Profile
Model Area 1
Case 3 – River Bed Lowered 5 Feet



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

Figure C-7
GROUNDWATER PROFILE
CASE 3

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

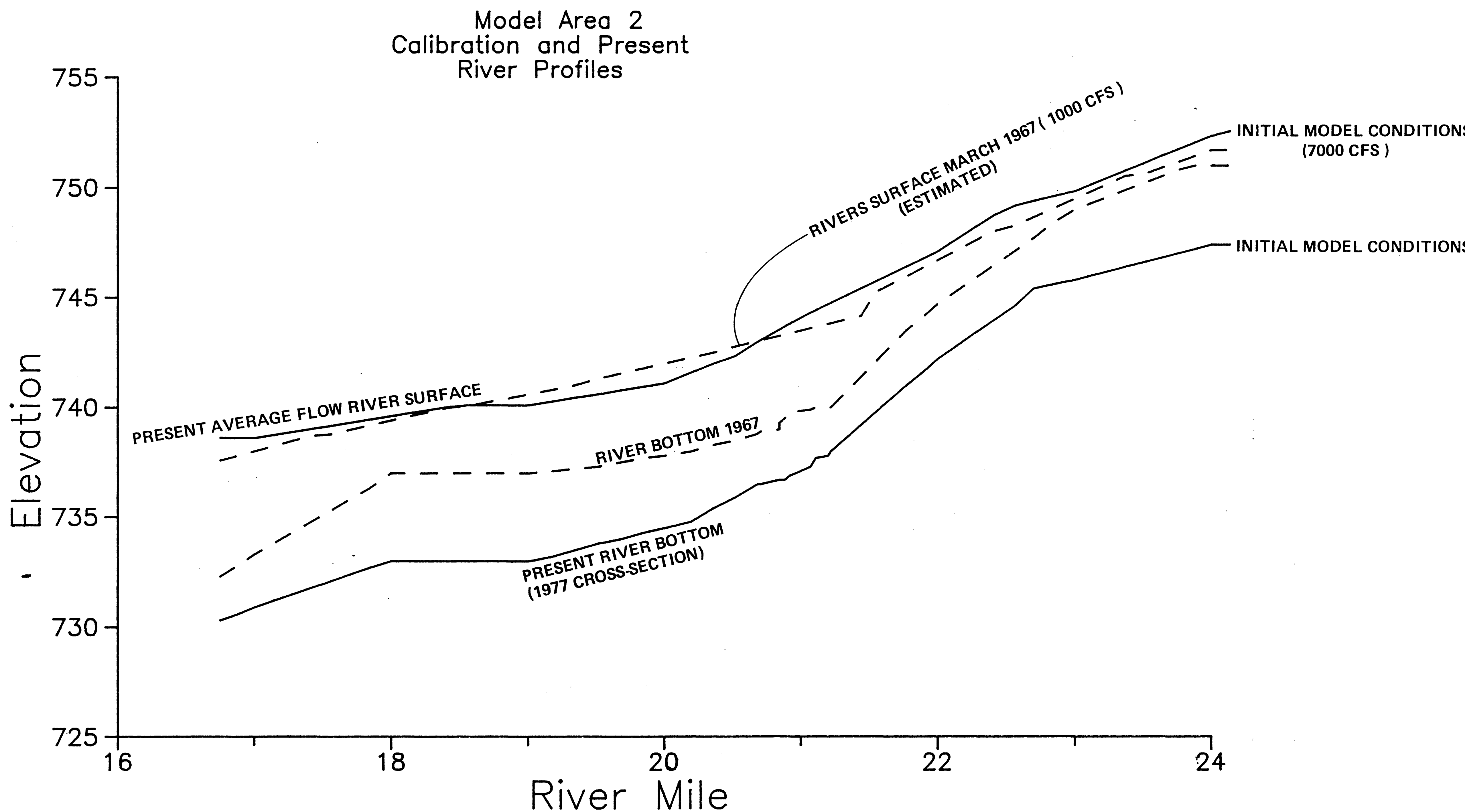


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Figure C-8
CALIBRATION AND PRESENT RIVER PROFILE

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

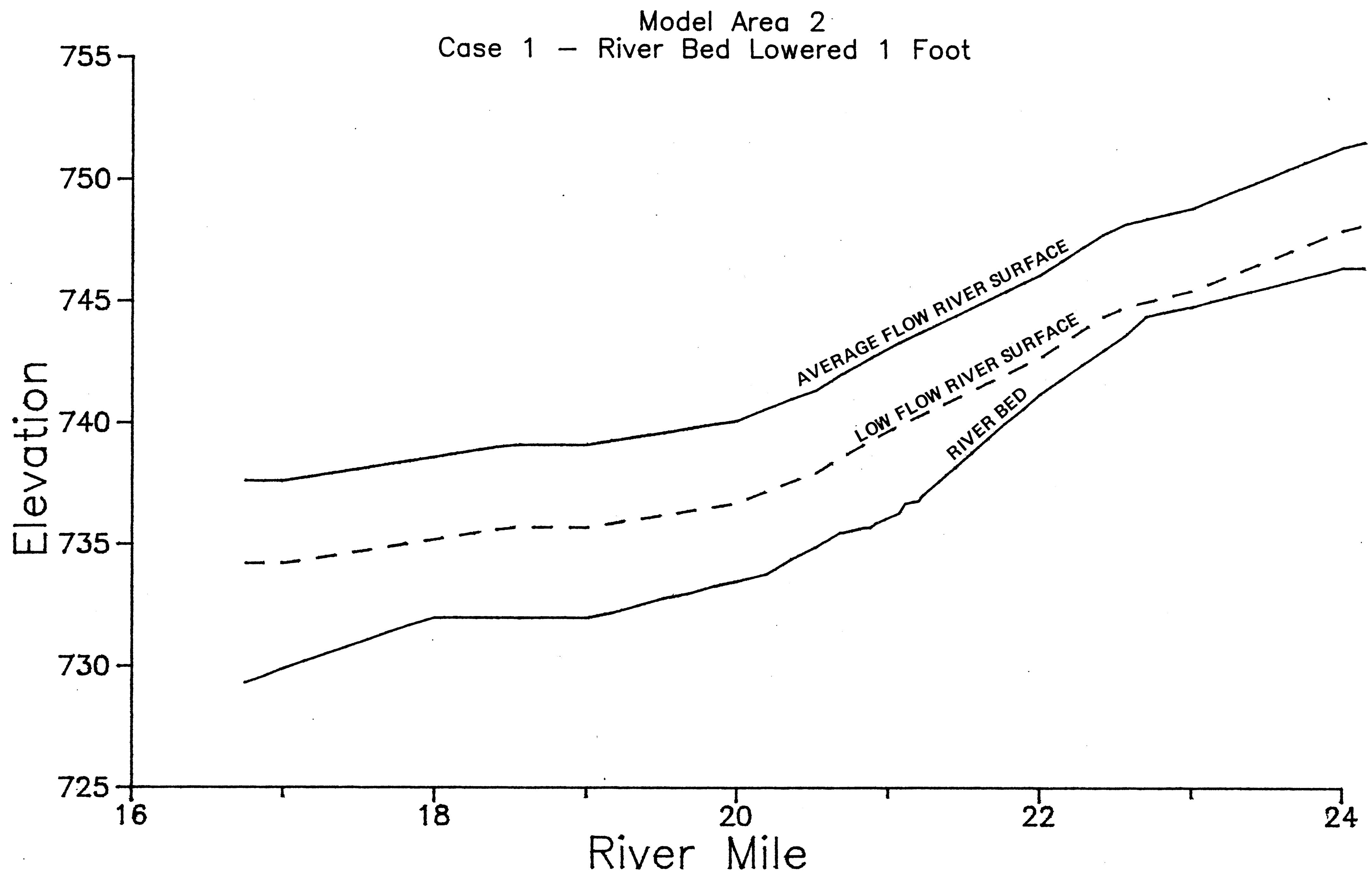

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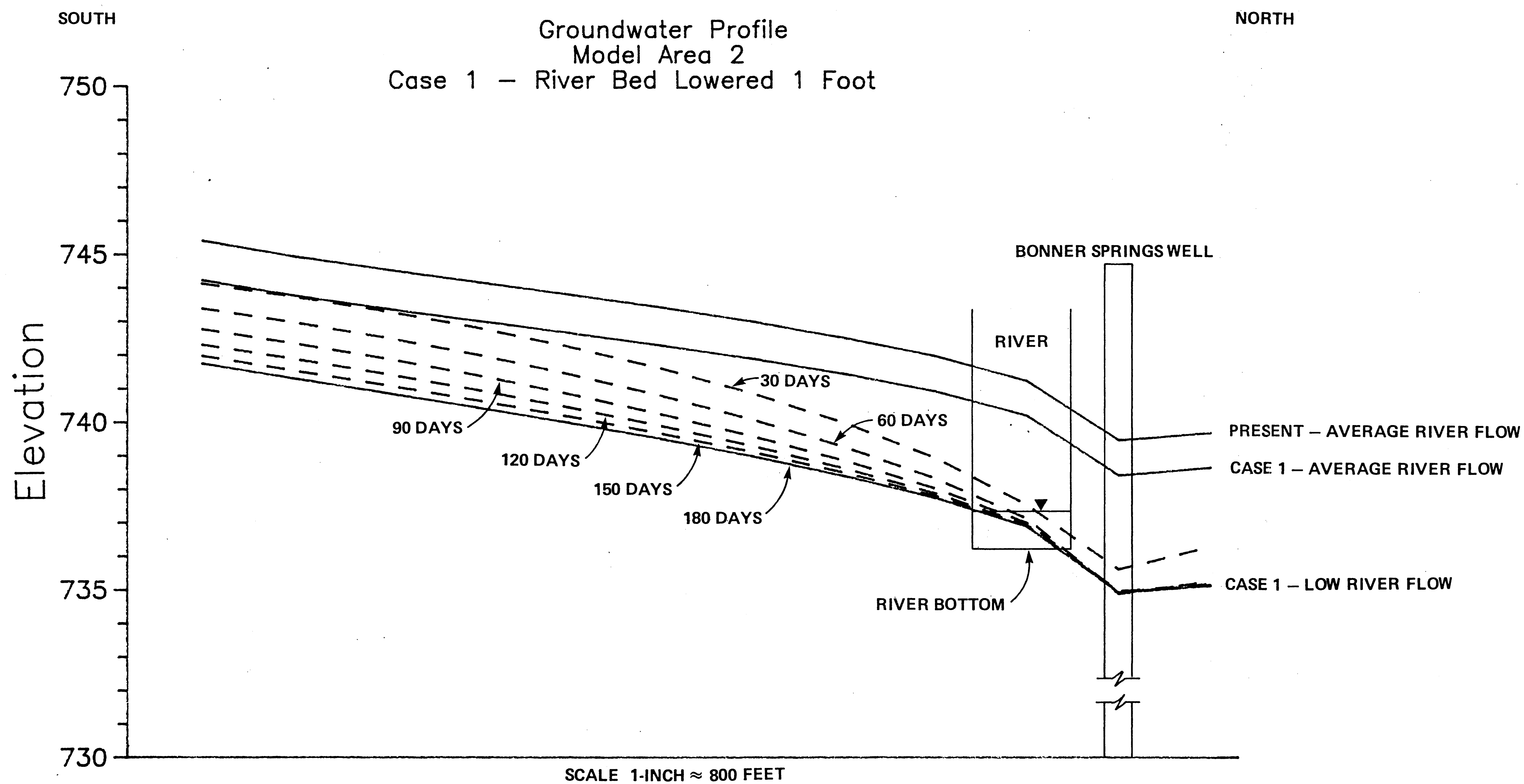
Figure C-9
RIVER PROFILE
CASE 1

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-10
GROUNDWATER PROFILE
CASE 1

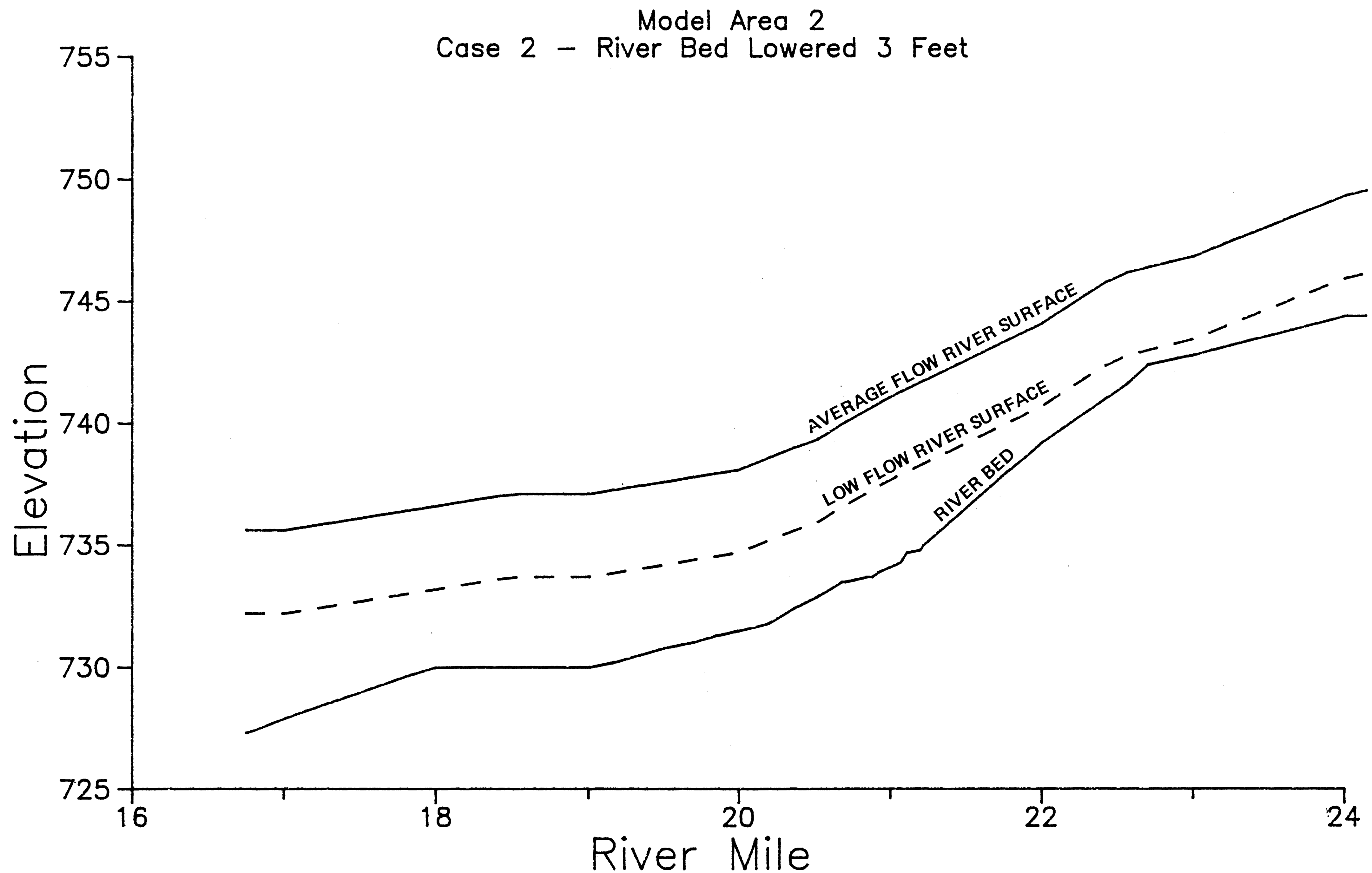

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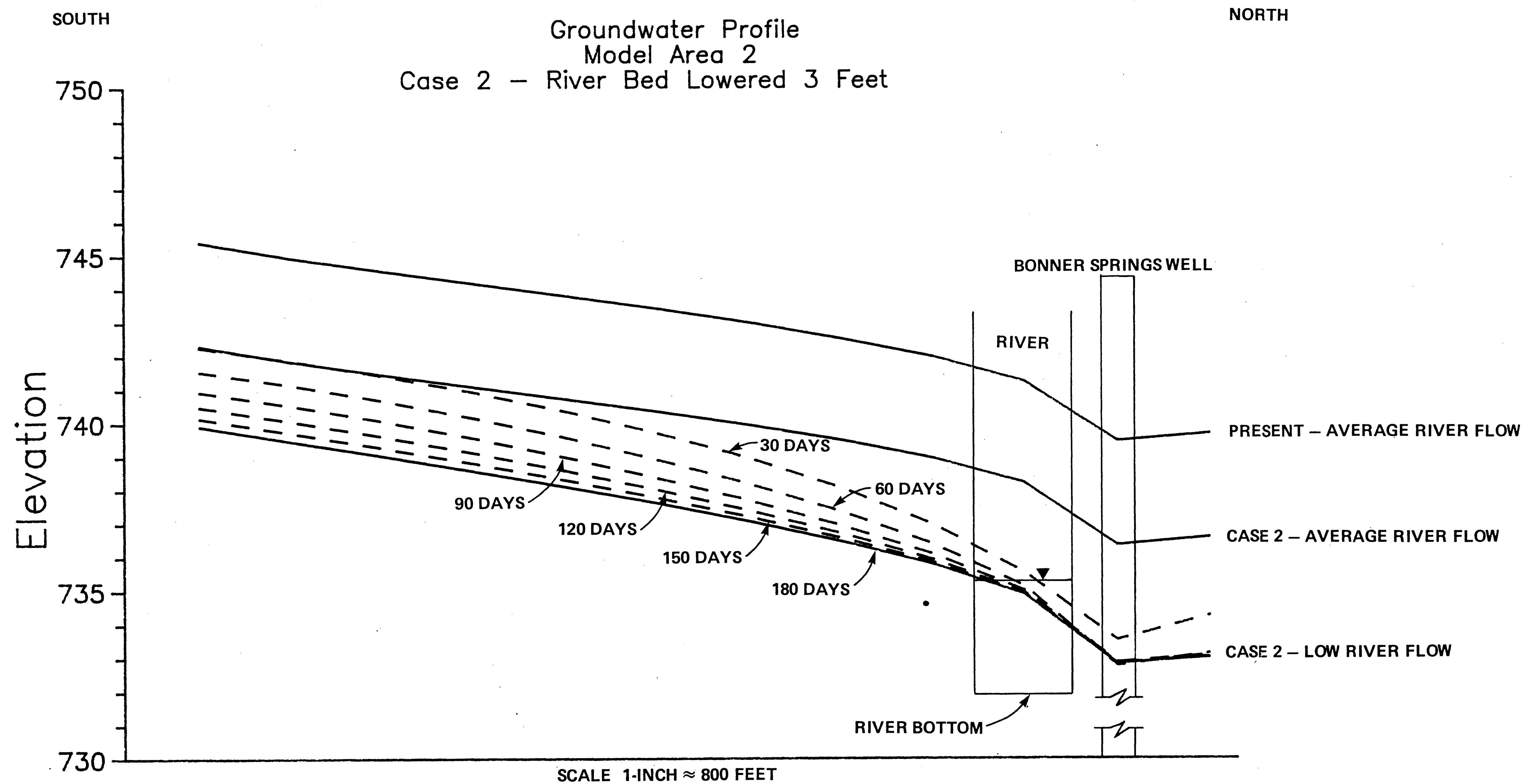
Figure C-11
RIVER PROFILE
CASE 2

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE : 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-12
GROUNDWATER PROFILE
CASE 2

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

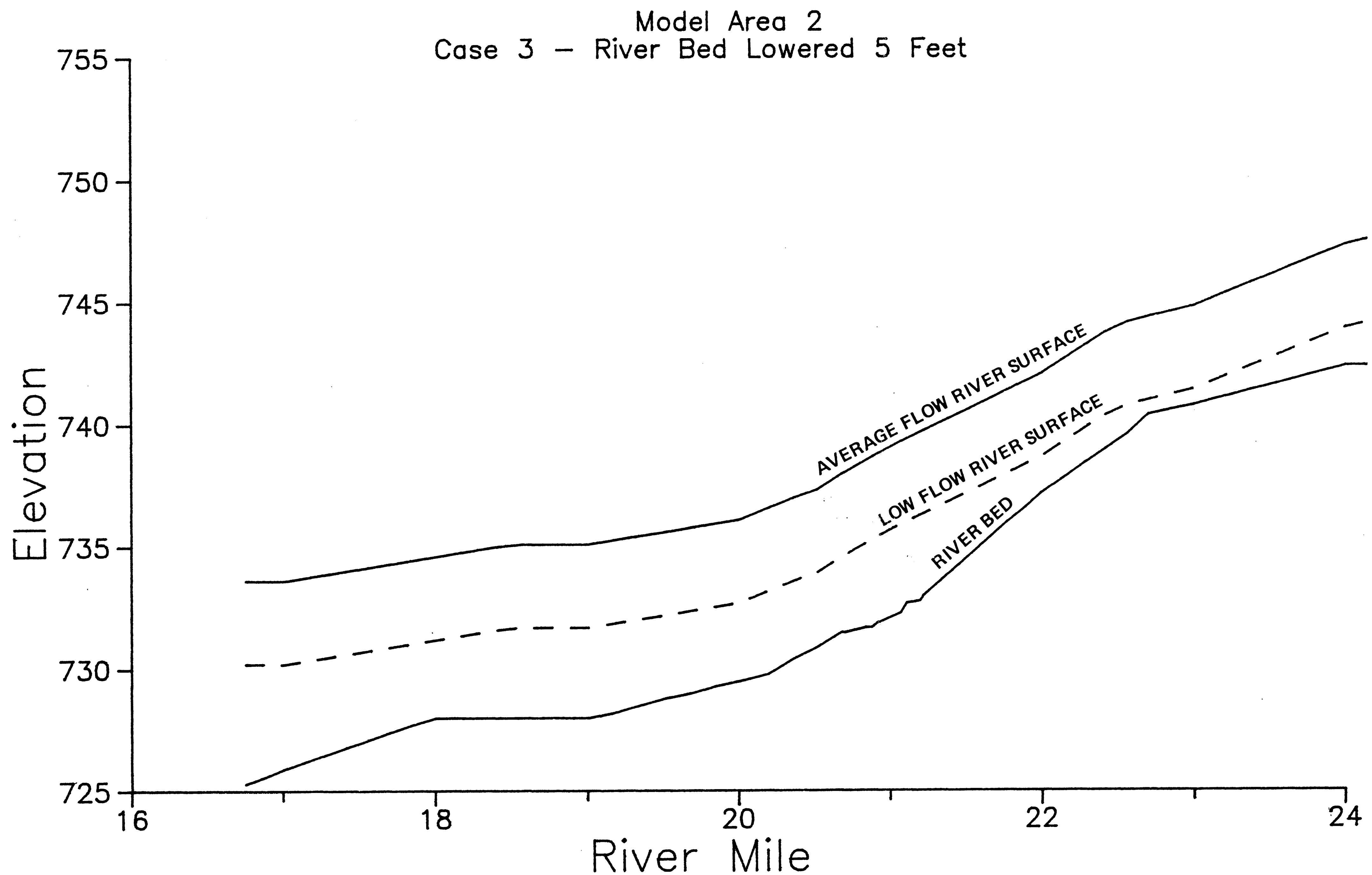

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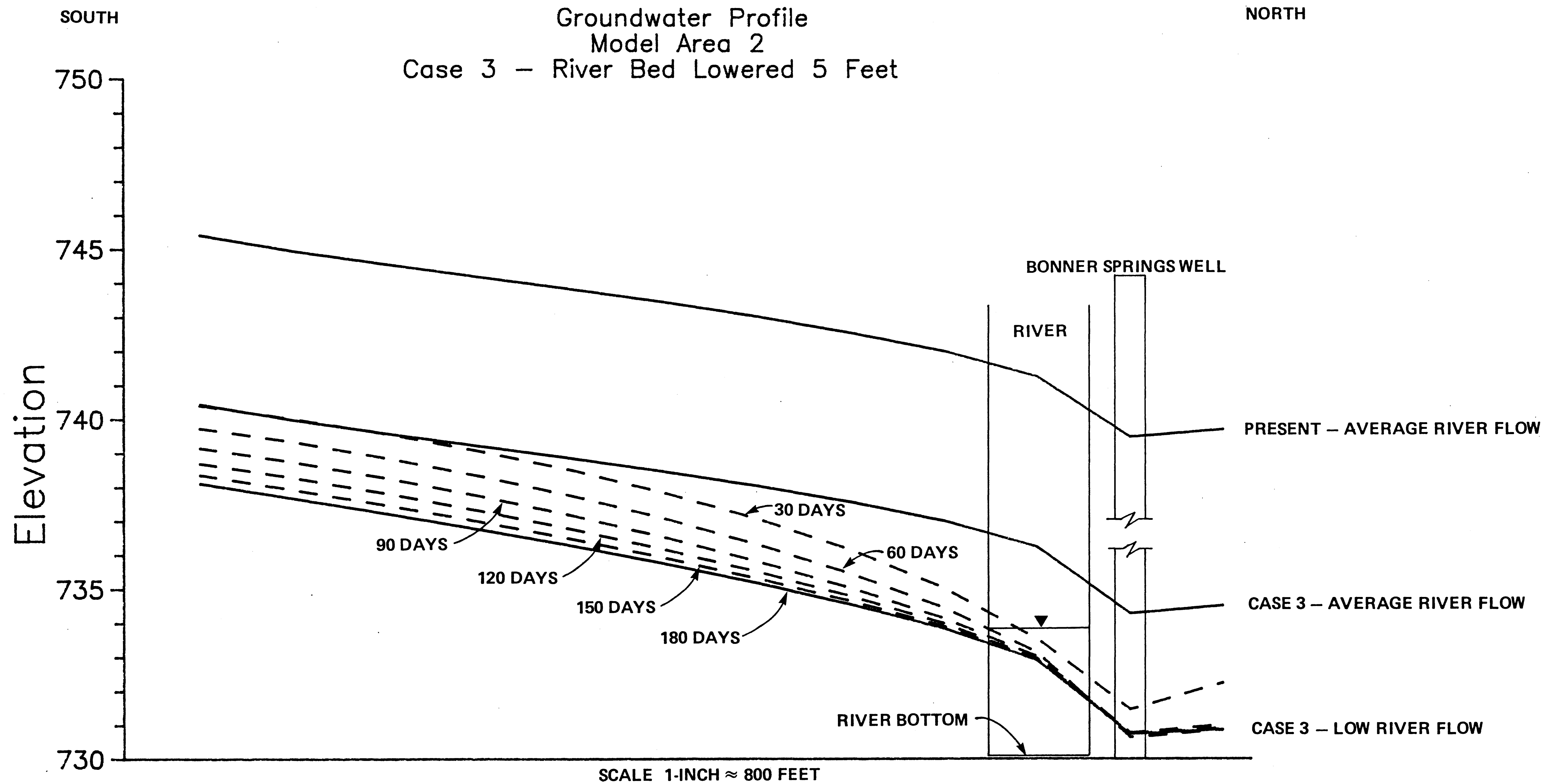
Figure C-13
RIVER PROFILE
CASE 3

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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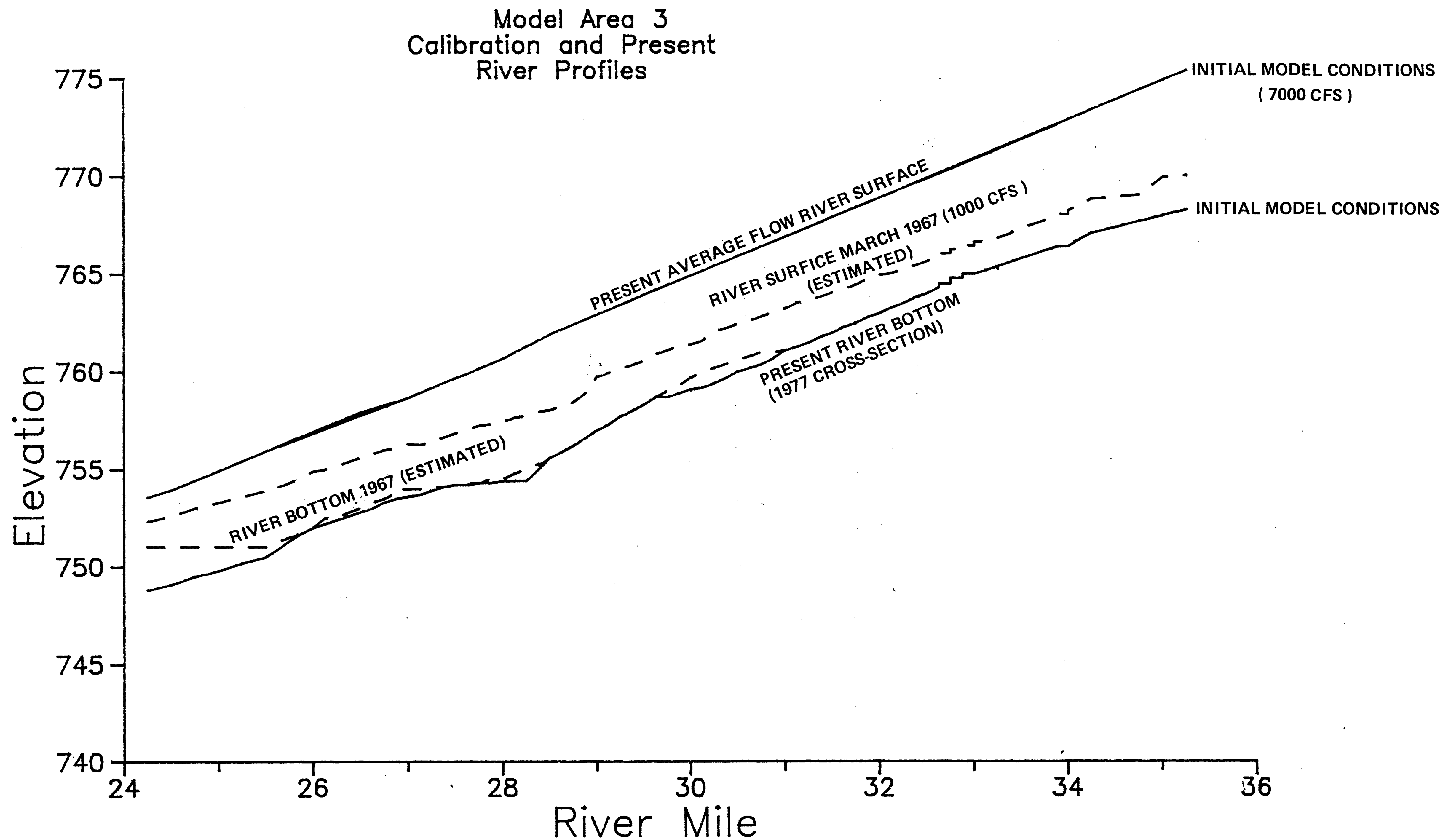
Figure C-14
GROUNDWATER PROFILE
CASE 3



USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

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Figure C-15
CALIBRATION AND PRESENT
RIVER PROFILE

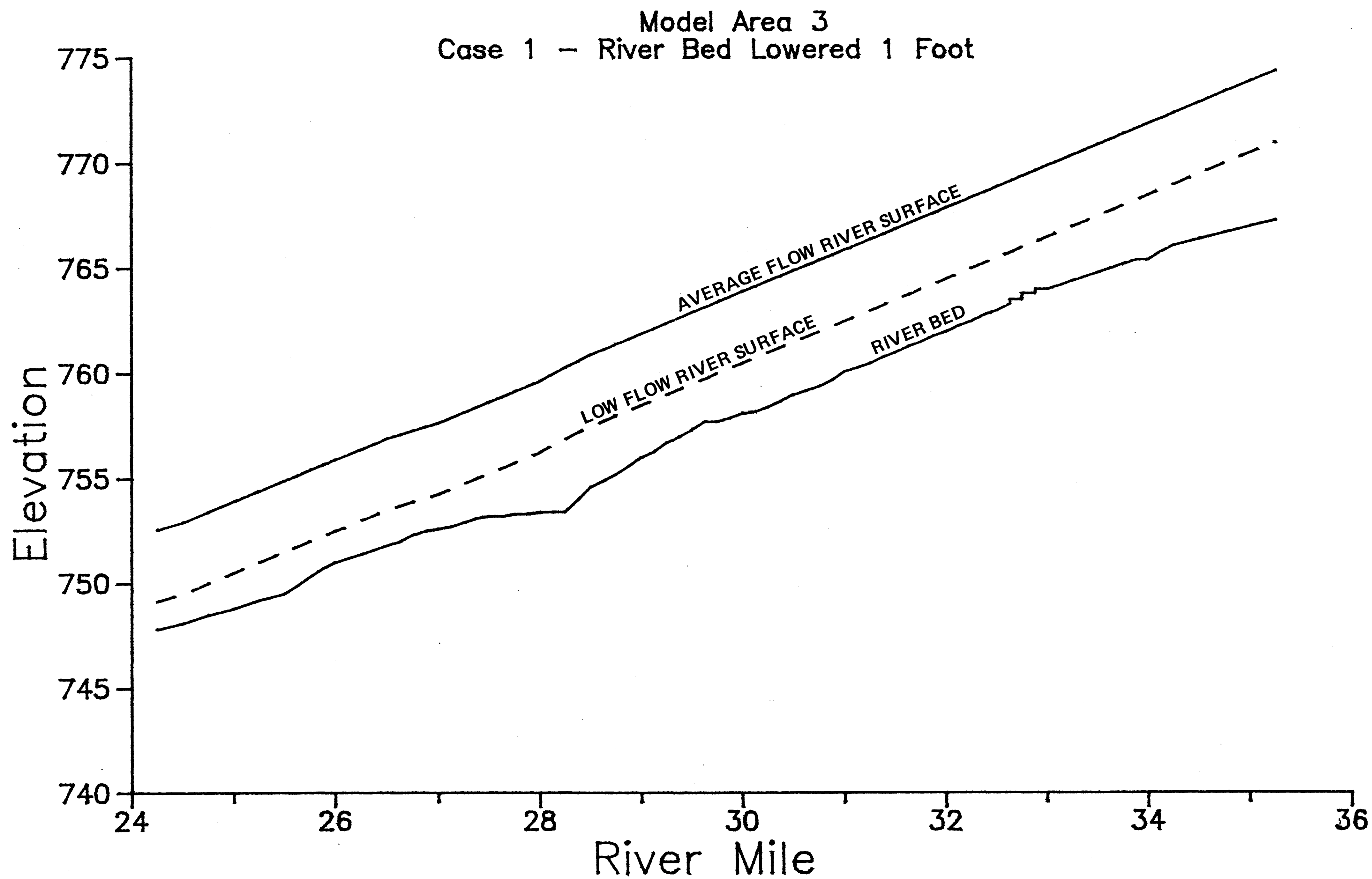
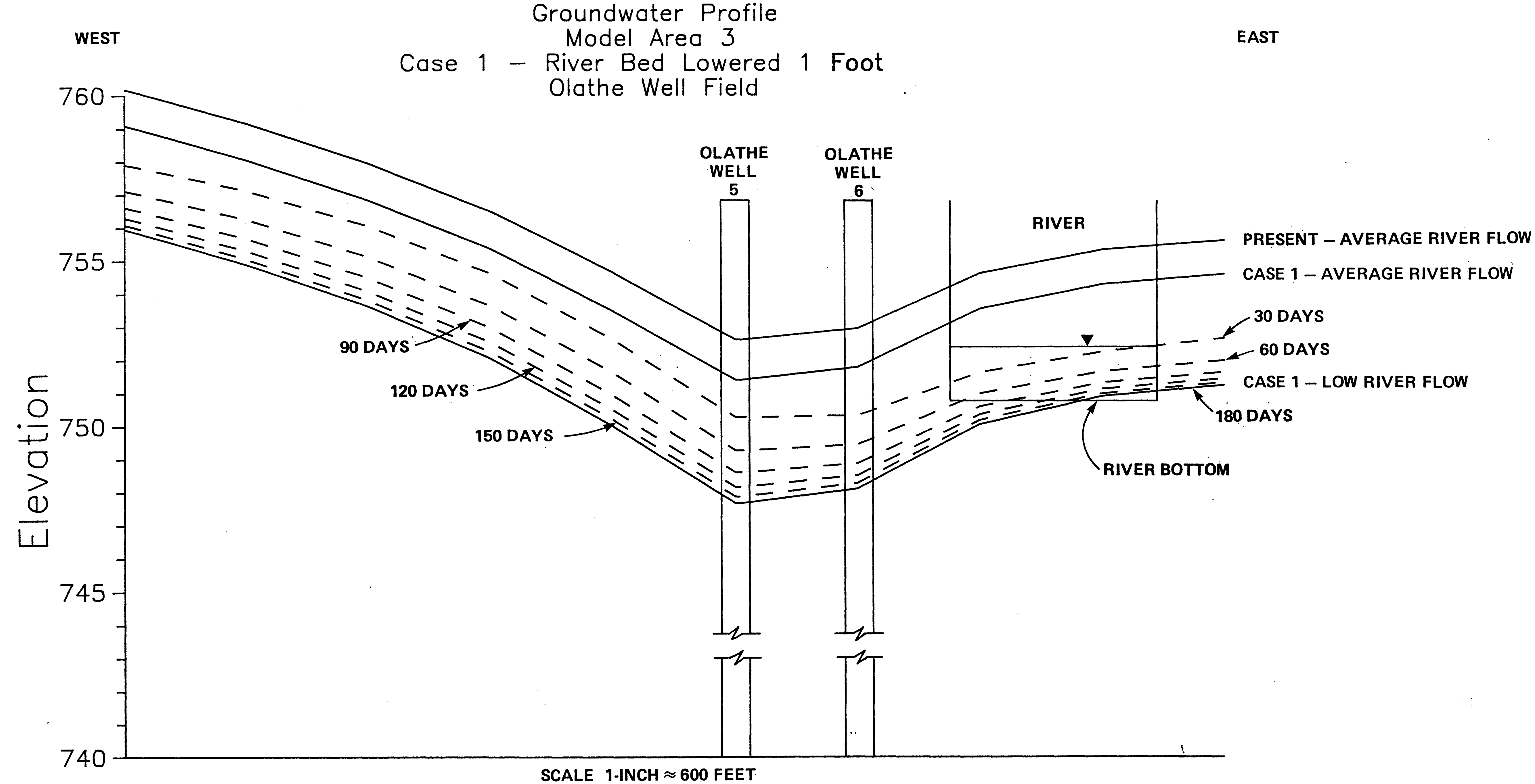


Figure C-16
RIVER PROFILE
CASE 1

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE : 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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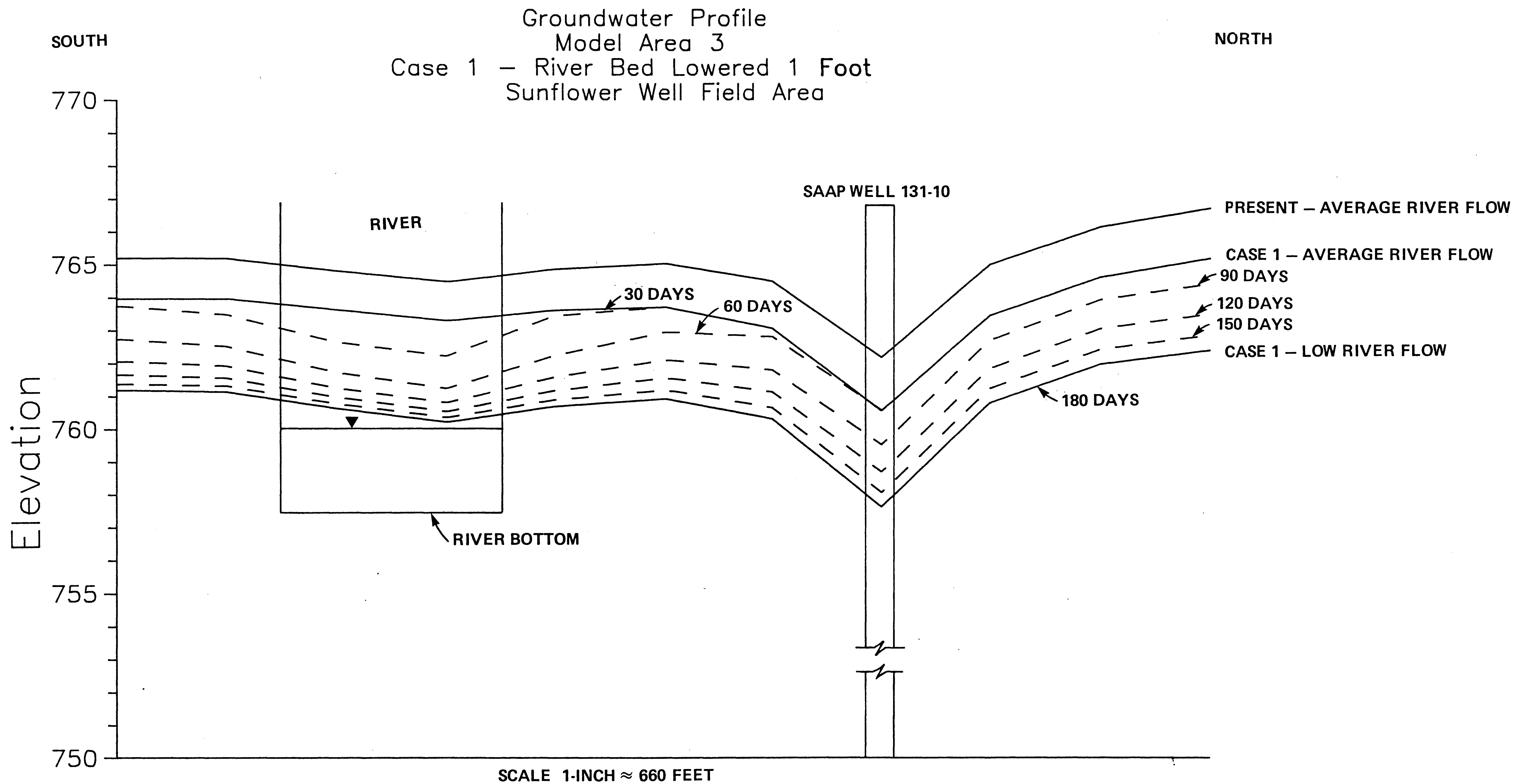
Figure C-17
GROUNDWATER PROFILE
OLATHE AREA
CASE 1



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-18
GROUNDWATER PROFILE
SAAP AREA
CASE 1

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

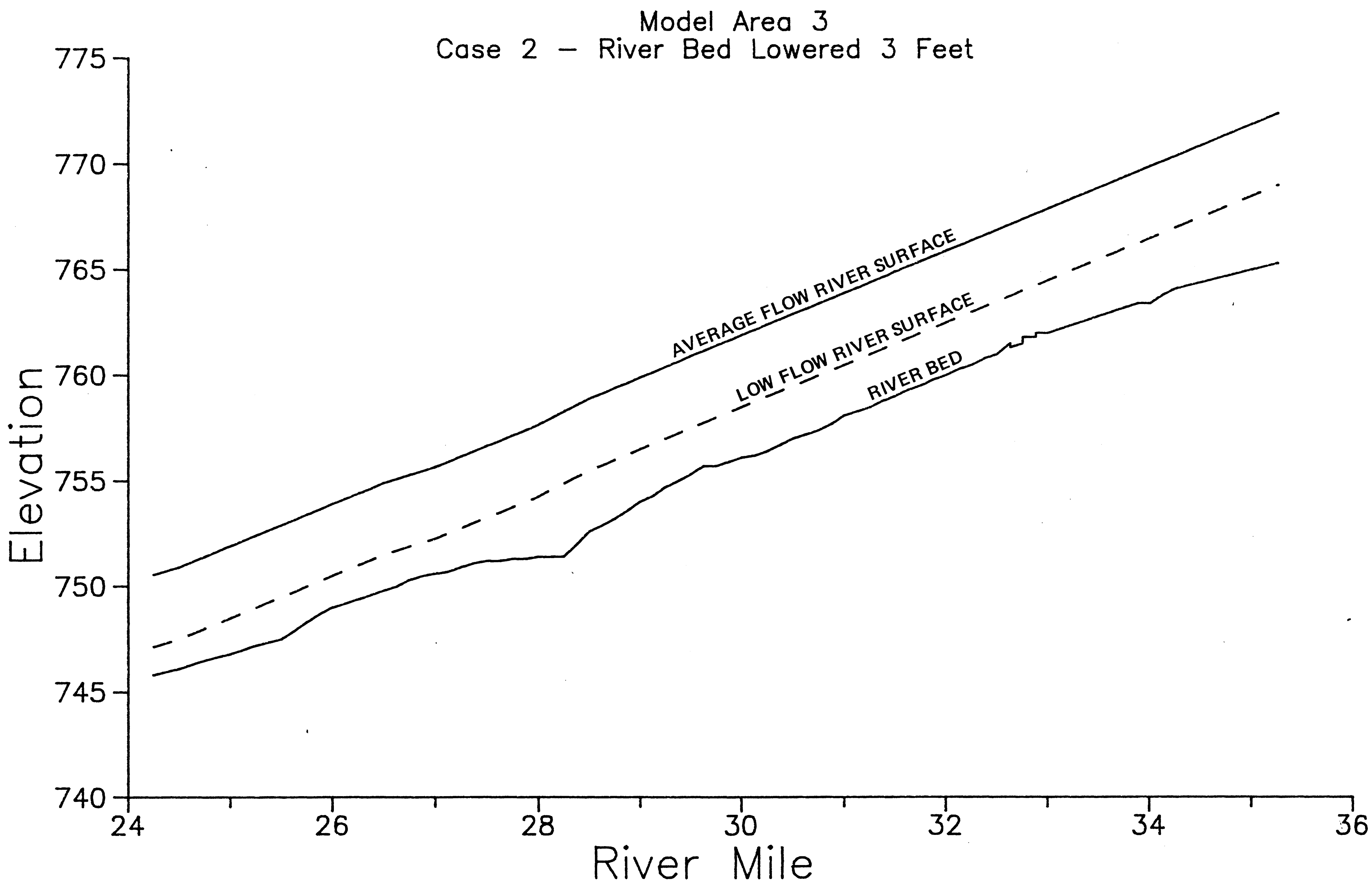

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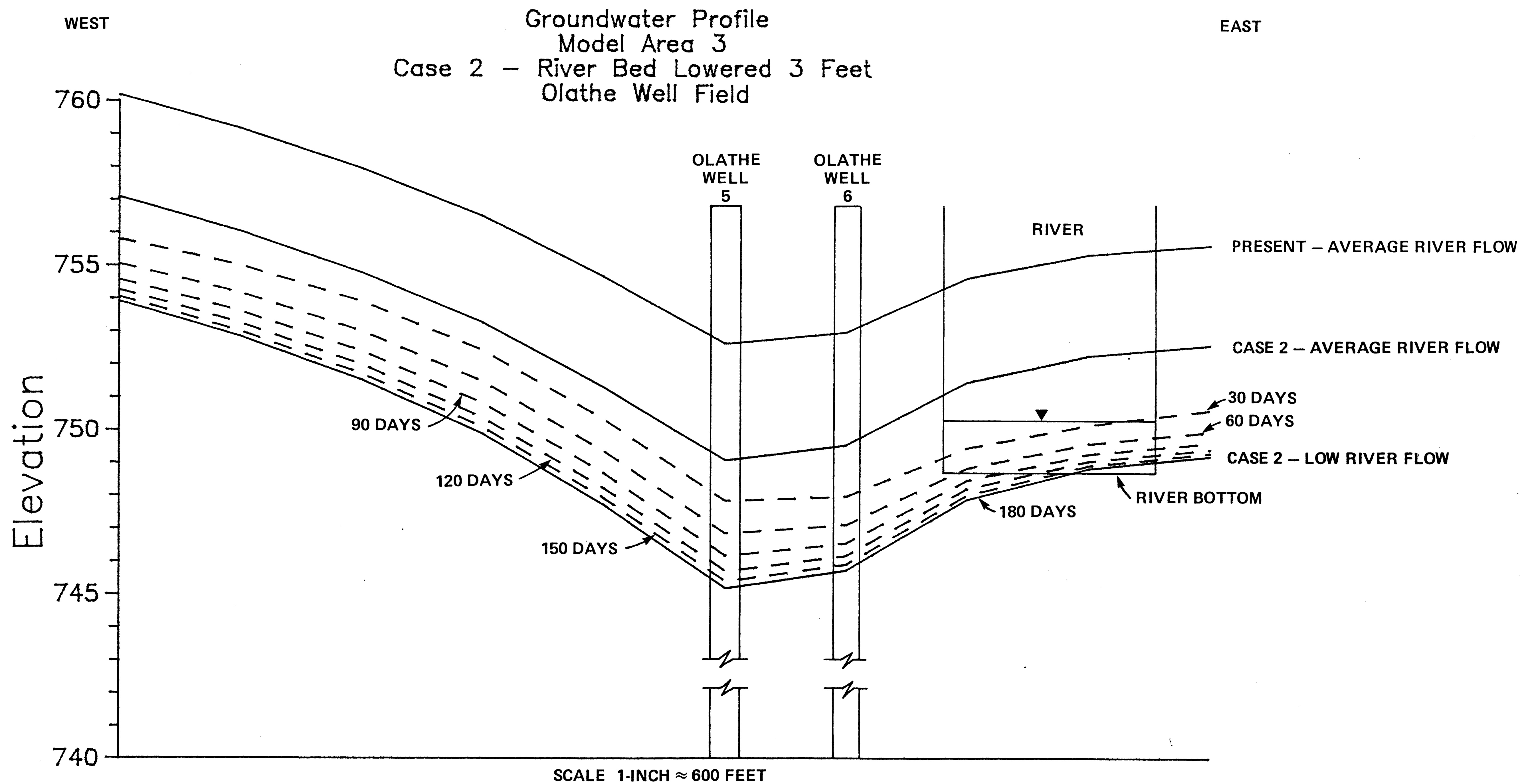
Figure C-19
RIVER PROFILE
CASE 2

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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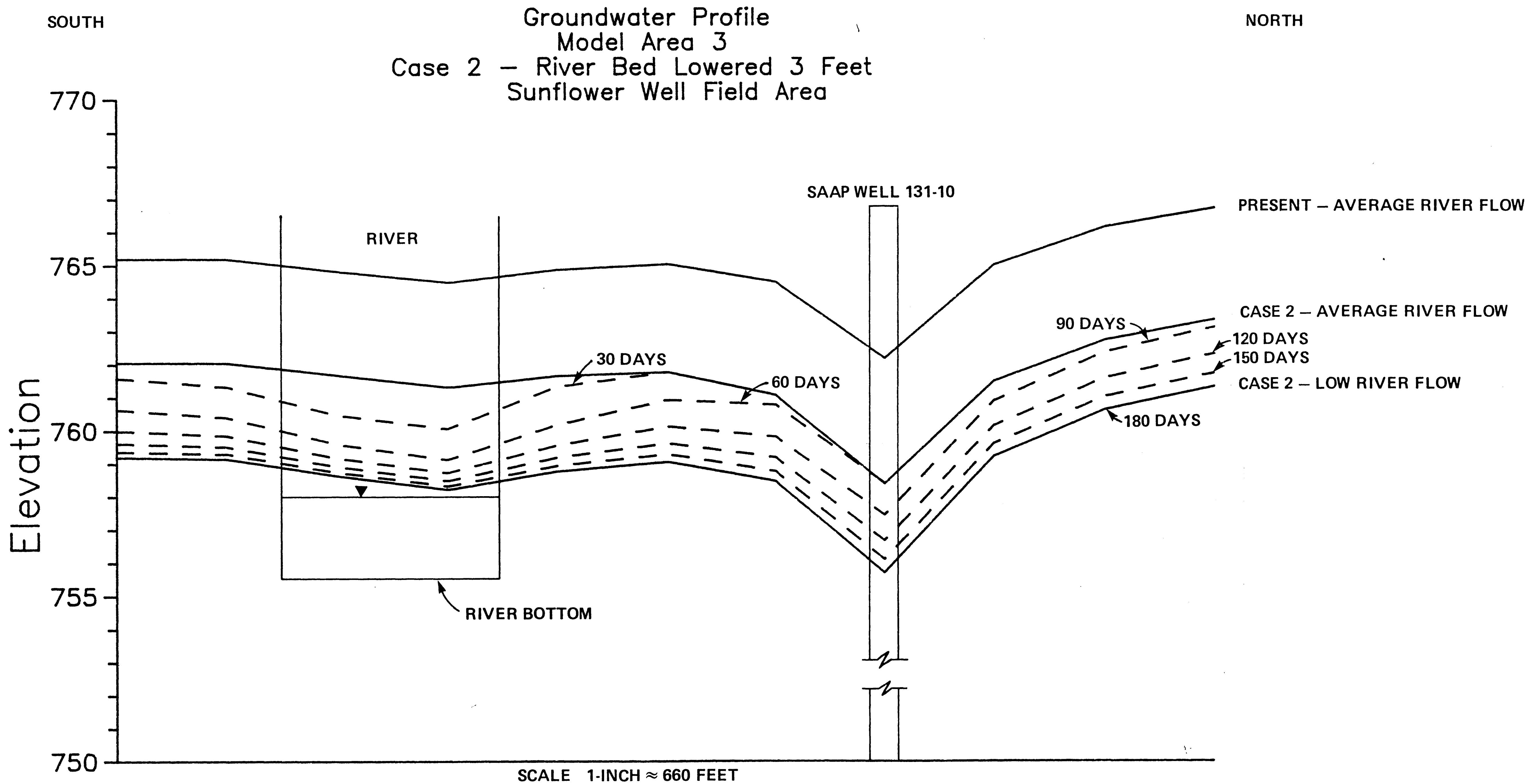
Figure C-20
GROUNDWATER PROFILE
OLATHE WELL FIELD AREA
CASE 2



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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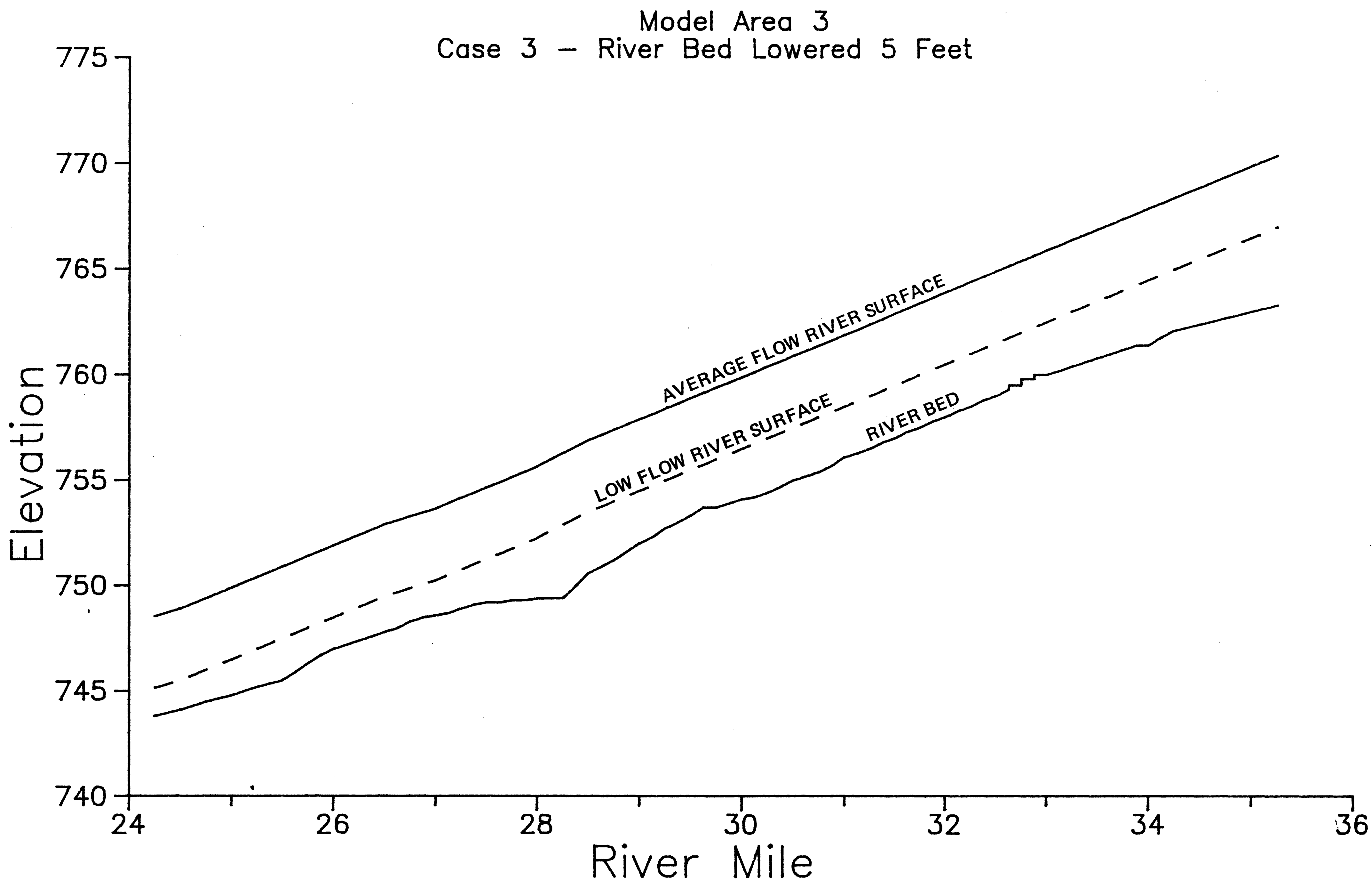
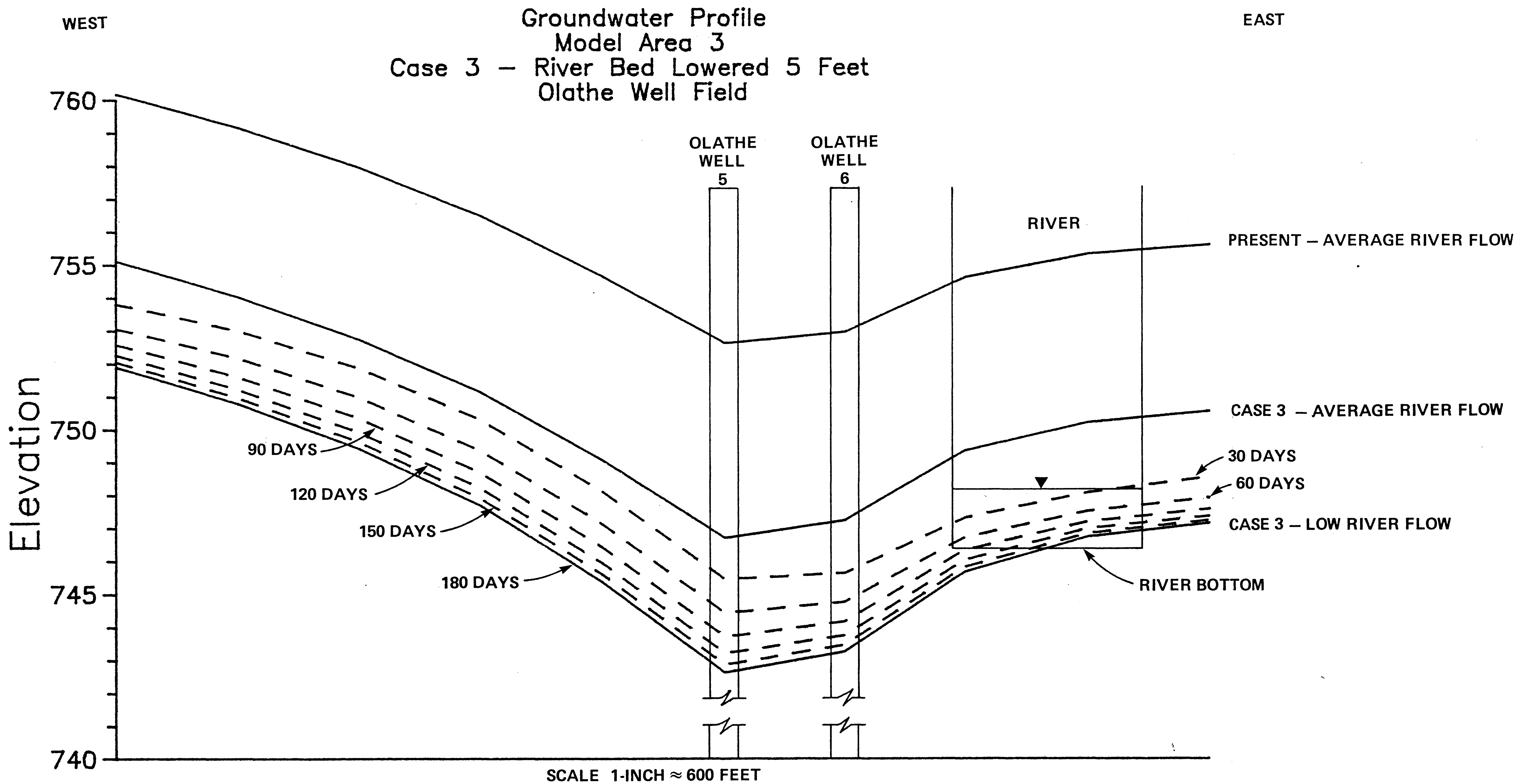
Figure C-21
GROUNDWATER PROFILE
SAAP AREA
CASE 2



Burns & McDonnell

Figure C-22
RIVER PROFILE
CASE 3

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE : 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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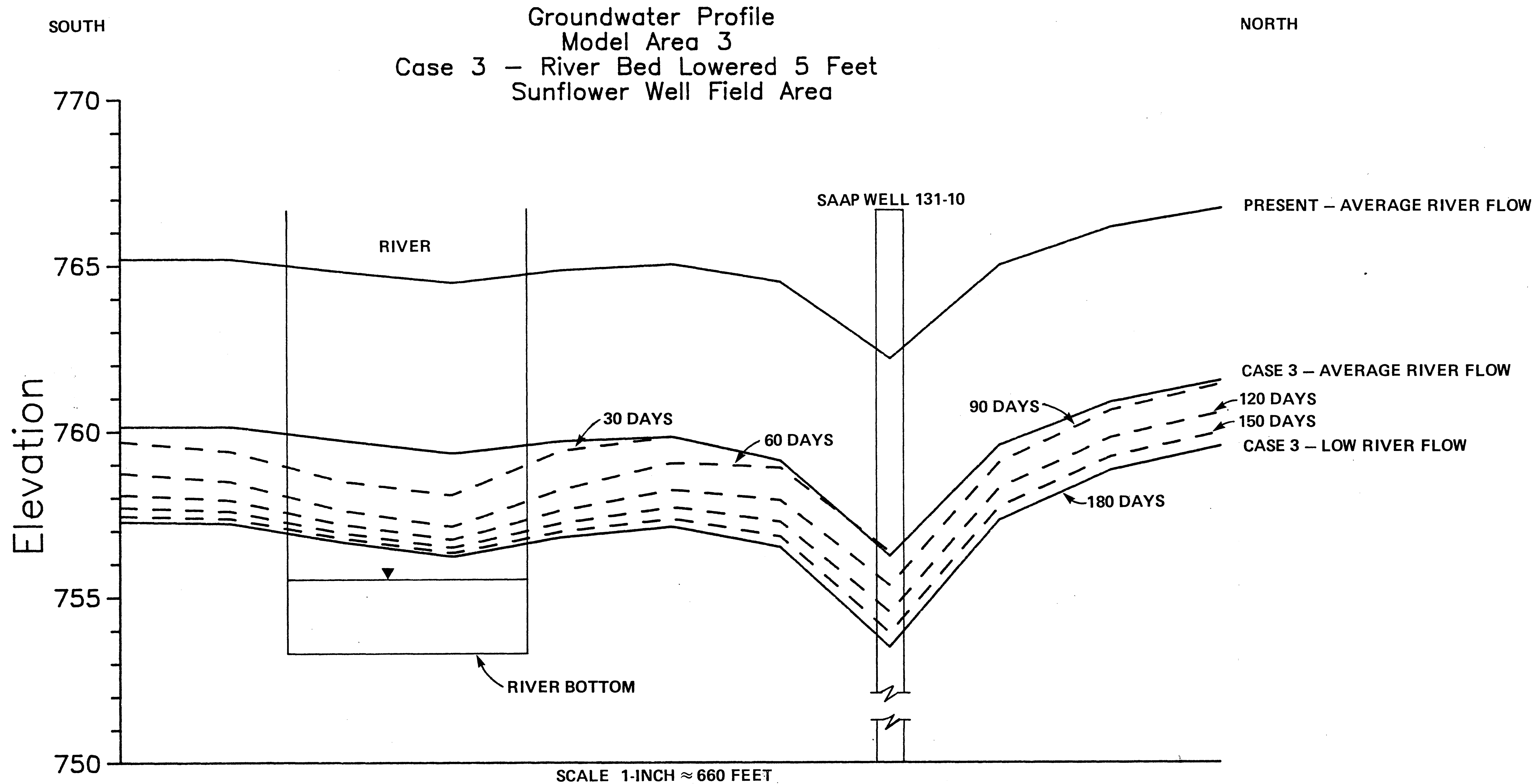
Figure C-23
GROUNDWATER PROFILE
OLATHE WELL FIELD AREA
CASE 3

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)



NOTE: 1. WELL LOCATION ARE NOT TO SCALE.
2. PUMPING WATER LEVELS ARE FOR MODEL NODES, NOT ACTUAL WELL PWL.

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Figure C-24
GROUNDWATER PROFILE
SAAP AREA
CASE 3

USKCDCOE 85-809-4-003 (GROUNDWATER STUDY)

APPENDIX D—PROJECT LETTERS AND MEMORANDA

Burns & McDonnell
MEMORANDUM

Date: August 25, 1986

To: Files

From: James Mellem/David Stous

Re: Johnson County Water District No. 1
USKCDCOE
Project No. 85-809-4-003

On August 22, 1986 a meeting was held with the following in attendance:

Bennett Kwan, Superintendent of Production, Water District No. 1
David Stous, Burns & McDonnell
James Mellem, Burns & McDonnell

A summary of the meeting is as follows:

1. Johnson County Water District No. 1 has 21 wells. Original design capacity was Wells 1 through 10 producing 1 million gallons a day and Wells 11 through 21 producing 0.5 MGD per day. Twelve years ago the well field would produce 10 to 11 MGD. Today, with all wells operating, approximately 7 MGD could be produced. Wells 1 through 10 will currently pump about 5 to 6 million gallons per day. Wells 11 through 21 pump only 1 to 2 million gallons per day.

   Mr. Kwan stated that he thought the loss in well capacity was due to collection line problems. They hope to clean and/or replace some of the lines in the near future and hope to recover the capacity of the system.

2. For the last 10 to 15 years the District has been treating approximately one-third of these wells every spring and fall. Each well is treated approximately every 18 months. The exception is Well No. 9 which has not responded to treatment and has too low of capacity to be used. The District has given up on Well No. 9 and may replace it.

   Specific capacity of the wells range from 40-70 gpm/ft. of drawdown. Original range was 70-130 gpm/ft. During the summer the wells were operated monthly to maintain the system and as a buffer for changing water demands.

3. In 1984 the intake on the Missouri River became operational. Consequently, in 1985 there was a significant reduction in groundwater pumpage. Prior to 1985 it had been about 2 billion gallons a year while 1985 was approximately 700 million gallons a year. The District's current method of operation is to blend well water with

river water during the winter. The well water raises the temperature of the river water which results in less freezing, better chemical reaction resulting in less use of chemicals. Mr. Kwan said that he expected future groundwater pumpage to be approximately that pumped in 1985.

4. Treatment costs for the wells run from $3,000 to $3,200 per well. The District allocates approximatly $50,000 per year to treat the wells.

5. Once or twice a year the District checks the static water level. They check the oil drip system about once a week. The remote control operation system upkeep is a significant expense.

6. Mr. Kwan said that there tends to be only minimal maintenance done on the wells. The wells have been giving good service with no major problems.

7. Mr. Kwan said that he would furnish us with the following data:

   a. Power consumption or the last five years.

   b. The current cost of power (cents per kilowatt hour).

   c. Approximate ballpark value of well maintenance cost (not including well treatment costs).

JWM/skb786

Burns & McDonnell
MEMORANDUM

Date: August 25, 1986

To: Files

From: James Mellem/David Stous

Re: Olathe, Kansas
USKCDCOE
Project 85-809-4-003

A meeting was held on August 22, 1986 with Rick Biery, Utilities Department, City of Olathe, David Stous, Burns & McDonnell and James Mellem, Burns & McDonnell. A summary of the meeting is as follows:

Openings in screen area

1. Mr. Biery said that the City contracts with Layne-Western to test the wells twice a year for specific capacity. Those wells needing treatment are then treated. They treat approximately 3 to 5 wells each year. Each well is treated about every 2 to 3 years. The costs for testing 11 wells is $3,500. The cost for treating Wells 1 through 4 is $3,545 per well; for Wells 5 and 9, $3,895; and for the remaining wells $4,655 per well. The difference is due to the different sizes of the wells.

2. Future pumpage is expected to be 4.5 MGD plus 5 percent or 4.725 MGD for the next 2 to 3 years. In two or three years the City expects to add another well. Occasionally during the summer, the City has to pump from 10 wells simultaneously. Current well field capacity is 6.5 to 7 MGD.

3. The City does not maintain its cost accounts in a manner that would allow separation of well operation and maintenance. Mr. Biery did say that they spend approximately $15,000 per year on outside contractors for rebuilding and repairing pumps. Another $5,000 per year is spent in-house on well maintenance materials.

4. Mr. Biery gave us copies of the state reports for the years 1982 through 1985, a spare report of Layne-Western's well testing, and copies of well drawdown measurements for wet and dry periods.

JWM/skb787

Burns & McDonnell
MEMORANDUM

Date: August 11, 1986

To: Project Files

From: Frank Shorney FJS

Re: Project Progress Review Meeting
for Groundwater Impact Study
B&McD Project 85-809-4-003

On July 30, 1986, the project progress review meeting was held for the groundwater impact study at the Kansas City District Corps of Engineers' office in Kansas City, Missouri. Those in attendance included:

Mr. Mike Bronoski, KCD COE
Mr. Tom Gurss, KCD COE
Mr. John Hoyt, KCD COE
Mr. Tom Prickett, Prickett & Associates
Mr. Dave Stous, Burns & McDonnell
Mr. Frank Shorney, Burns & McDonnell

The following items were discussed:

- The collection of data for the groundwater impact study was reported to be 90 percent complete. Three separate models are being developed for the groundwater study including Model No. 1 for the Johnson County Water District No. 1 area, Model No. 2 for the Bonnor Springs area and Model No. 3 for the Olathe-Sunflower-DeSoto area.

- The groundwater models will be developed and calibrated for the years which have the most groundwater level data available. The models will also be used to check data during other periods of record. Items which can be adjusted in the model include permeability, condition of river bottom, flow from groundwater recharge, and aquifer thickness.

- Much of the data for the groundwater model will originate from the Kansas Geological Survey Report No. 206 by Stewart W. Fader. Water level data in observation wells from 1966 through 1969 will be used along with bedrock data. "Average" water level information will be used as opposed to "specific" water level data since the water level data fluctuates widely. A direct connection apparently exists between the river and the groundwater reservoir.

- Soil boring test hole data has been obtained and plotted. This information was obtained from the Kansas Department of Transportation, Kansas Geological Survey and USGS (USGS duplicates much of the KGS information).

- A complete printout of water rights has been obtained from the state and information on irrigation wells has been plotted for each model. Water well information from the Layne-Western Company has been obtained along with well log information from the Kansas Department of Health and Environment (began collecting information on wells in the early 70's).

- River stage data was plotted for the DeSoto River gauge from 1973 to 1977 and a downward trend in the water level was observed. Engineer will attempt to plot river stage data with observation well levels on the same graph for the purpose of comparison. Data collection at the Bonnor Springs gauge stopped in 1973. KCD COE said Johnson County Water District No. 1's rock jetty improvements were added to the river in 1967 which will impact river stage readings in this area.

- Engineer noted that information from the Kansas Department of Transportation pertained primarily to bridge crossings of the Kansas River and contained mostly information on bedrock locations.

- Modeling for the groundwater impact study will include a system of grids of approximately 10-acre plots for each model. The program will permit each grid to contain information on river stage data, condition of bottom, 1967 water surface data, bedrock elevations, and permeability. Model output will include water levels in the groundwater aquifers.

- The best data base for the study is the 1960's data from the Fader report. The groundwater model will be calibrated to match 1960 data whenever possible. High flow stages in the river may not produce accurate groundwater impacts in the model since the model will be calibrated for low flow conditions.

- Mr. Prickett said the aquifer thickness ranges from 30 to 50 feet. He said the aquifer appears to be more permeable closer to the bedrock. The stripping off of less permeable materials from the river by dredgers will probably impact river bed permeability.

- KCD COE provided river profiles and river cross sections taken in 1967. KCD COE noted that substantial river degradation occurred in the 1960's below Bonner Springs and that this trend seemed to stabilize during the 1970's.

- Mr. Prickett said the groundwater model will deal with water flow and levels, but can also be modified to evaluate water quality under the code name "PLASRAN."

- After reviewing study procedures, Engineer and Mr. Prickett were instructed by KCD COE to proceed with the groundwater modeling effort for the final report.

- o Mr. Tom Gurss said he may visit Engineer's office in the next several weeks to observe the operation of the computer model.

ACTION REQUIRED:

- o Engineer to proceed with preparation of report draft for KCD COE's review.

FLS/skb765

cc: Mr. Mike Bronoski, KCD COE
Mr. Dave Stous, B&McD