ASSESSMENT OF GROUND-WATER CONTAMINATION

IN THE ALLUVIAL AQUIFER NEAR

WEST POINT, KENTUCKY

By Mark A. Lyverse and Michael D. Unthank

U.S. GEOLOGICAL SURVEY

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DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, rather than the inch-pound units, the following conversion factors may be used:

Multiply inch-pound unit	By	To obtain metric unit
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot (ft)	0.3048	meter (m)
millimhos per meter at 25° Celsius (mmho/m)	1.000	millisiemens per meter at 25° Celsius (mS/m)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
picocurie (pCi)	0.0370	becquerel (B_q)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

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ABSTRACT

Well inventories, water-level measurements, ground water quality analyses, surface geophysical techniques (specifically, electromagnetic techniques), and test drilling were used to investigate the extent and sources of ground-water contamination in the alluvial aquifer near West Point, Kentucky. This aquifer serves as the principal source of drinking water for over 50,000 people.

Ground water in the alluvial aquifer is generally unconfined and flows in a northerly direction toward the Ohio River. Two large public supply well fields and numerous domestic wells are located in this natural flow path.

High concentrations of chloride in ground water have resulted in the abandonment of several public supply wells in the West Point area. Chloride concentrations in water samples collected for this study were as high as 11,000 milligrams per liter. Electromagnetic techniques indicated and test drilling later confirmed that high concentrations of chloride exist in the alluvial aquifer near abandoned oil and gas exploration wells.

The potential for chloride contamination of additional wells exists in the study area and is related to the proximity of the water wells to improperly abandoned oil and gas exploration wells and to gradients established by drawdowns associated with pumped wells. Periodic use of surface geophysical methods, in combination with ground water sampling at additional observation wells, could be used to monitor significant changes in ground-water quality related to chloride contamination.

INTRODUCTION

The principal source of water for the Hardin County Water District #1 (HCWD #1) is a well field near West Point, Kentucky, where water is obtained from an alluvial aquifer. This aquifer also provides water for the City of West Point and the U.S. Army Installation at Fort Knox, Kentucky. The supply wells of HCWD #1 and Fort Knox comprise one of the largest well fields in Kentucky serving as the principal source of drinking water for over 50,000 people.

During the past several years, water samples collected from numerous supply wells near and within HCWD #1 have contained high concentrations of chloride. In addition, two HCWD #1 supply wells have recently produced water containing up to 3 mg/L of oil and grease, and water from at least one well had an elevated level of gross-alpha radioactivity.

Manuscript approved for publication September 14, 1988

The U.S. Geological Survey (Survey), in cooperation with HCWD #1, conducted a preliminary study to determine the extent and possible sources of ground-water contamination in the alluvial aquifer in the vicinity of the HCWD #1 well field. This report summarizes the results of this investigation.

Purpose and Scope

The purposes of this study were to (1) define and describe the areal extent of chloride, oil and grease, and radionuclide (specifically gross alpha) contamination in the vicinity of the HCWD #1 well field, (2) identify possible sources of these contaminants, and (3) evaluate the potential for contamination of other existing or proposed wells. These objectives were met by compiling and reviewing available hydrologic, geologic, land- and water-use data, and collecting and analyzing supplemental hydrogeologic data from test wells, surface geophysical studies, and water-quality sampling programs.

Location and Extent of Study Area

The study area is in north-central Kentucky and is limited to approximately 5.7 mi^2 of the Ohio River alluvial aquifer in a cut-off meander about 2.6 miles west-southwest from West Point, Kentucky (fig. 1). The study area includes well fields for the HCWD #1 and Fort Knox Military Reservation.

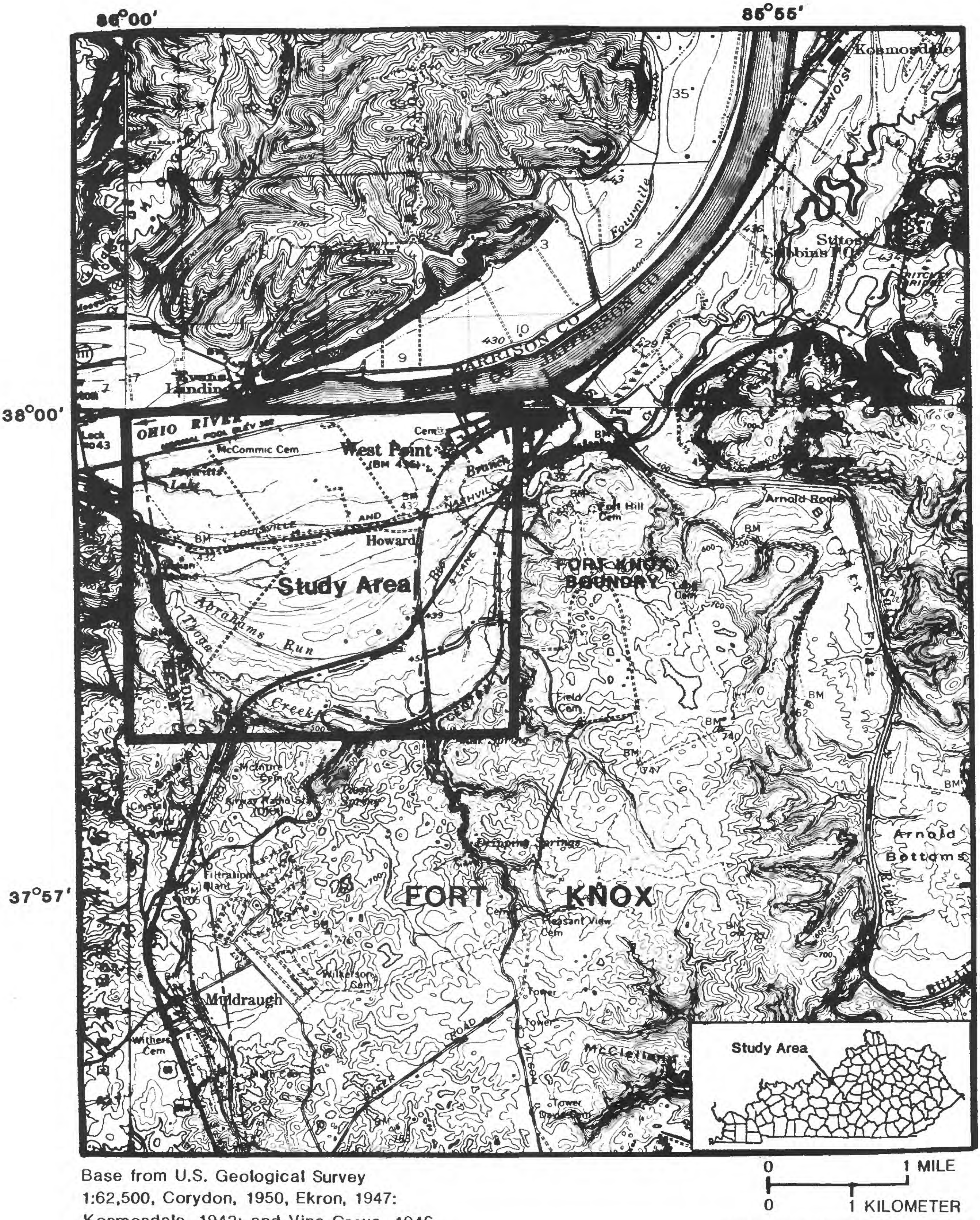
Physical Features and Land Use

The most prominent physical features of the study area are the rounded hills that range in altitude from about 400 feet at the Ohio River to 450 feet near Tioga Creek. The area is divided by the Louisville and Nashville Railroad track which separates privately owned lands north of the track from the Fort Knox Military Reservation to the south. Privately-owned land outside the boundaries of Fort Knox is sparsely populated with single family farms that produce corn, hay, livestock, and dairy products. The military land in the study area south of the track is essentially uninhabited. Drainage is generally from east to west in intermittent streams that drain toward Prewitts Lake and to Tioga Creek. Both the lake area and the creek drain to the Ohio River.

The HCWD #1 well field is in the extreme northwest corner of the study area near the west end of a Fort Knox well field that is parallel to the Ohio River (fig. 2). Average daily pumpage from the HCWD #1 well field averaged about 2.1 million gallons per day (Mgal/d) during the fall of 1987, (William Smallwood, Manager, HCWD #1 Water Treatment Plant, oral commun., April 1988). Average daily pumpage from the Fort Knox wells averaged about 2.2 to 2.3 Mgal/d for the same period (Kenneth Vowels, Chief, Sanitation Branch, Fort Knox Military Reservation, oral commun., April 1988).

Methods of Investigation

A preliminary characterization of the movement and quality of ground water in the alluvial aquifer near West Point was accomplished using literature sources and water-quality and water-level data collected in the fall of 1987. A surface geophysical survey was used to delineate areas of possible chloride



Base from U.S. Geological Survey
1:62,500, Corydon, 1950, Ekron, 1947:
Kosmosdale, 1942: and Vine Grove, 1946.

0 1 MILE
0 1 KILOMETER
CONTOUR INTERVAL 20 FEET
DATUM IS SEA LEVEL

Figure 1.--Location of study area.

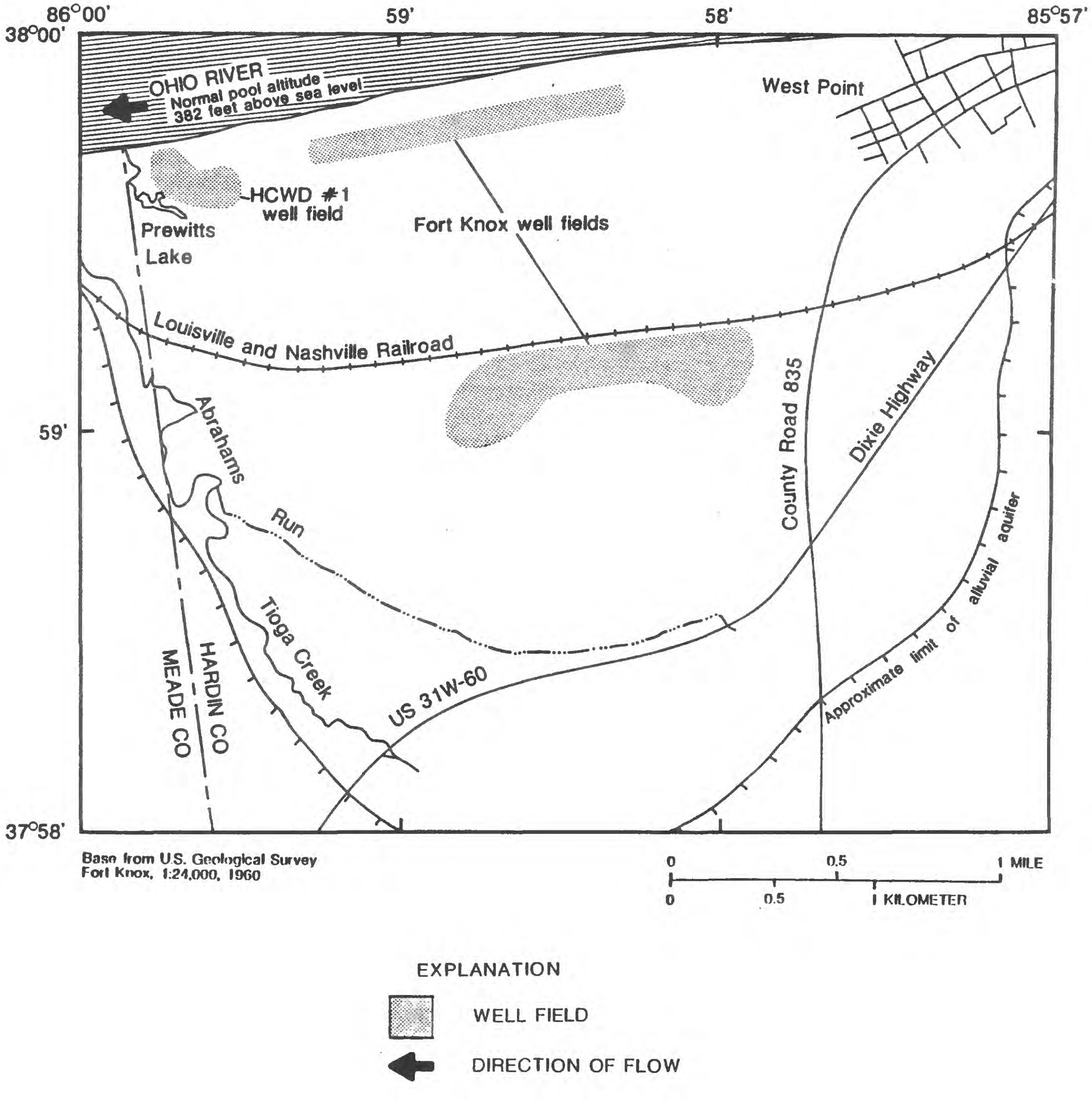


Figure 2.--Location of Hardin County Water District #1 (HCWD#1) and Fort Knox well fields.

contamination. In these areas, test drilling was used to verify the geophysical survey. Monitoring wells were completed in several of the test holes to provide additional hydrologic data.

GEOLOGY

The study area is underlain by unconsolidated glacial outwash and other alluvial deposits of Pleistocene and Holocene age that average about 100 feet in thickness. These sediments are underlain by the consolidated Borden Formation of Early Mississippian age and below that the New Albany Shale of Late Devonian and Early Mississippian age. Limestones of Devonian and Silurian age underlie the New Albany Shale. These consolidated rocks are relatively uniform in structure and dip gently to the west. A generalized columnar section showing average thicknesses and water-bearing properties of these units is presented by Palmquist and Hall (1960).

HYDROGEOLOGY OF THE ALLUVIAL AQUIFER

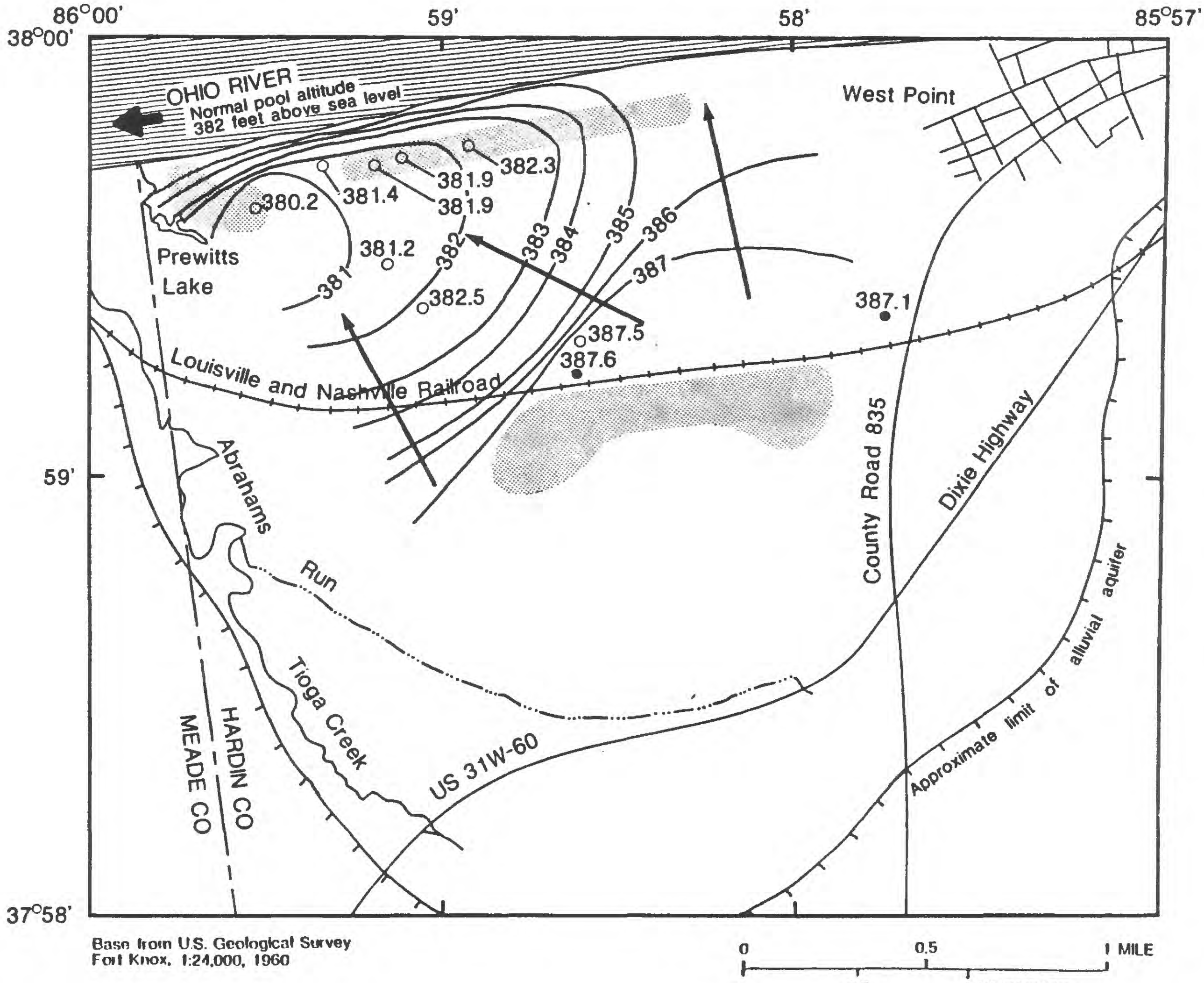
Sources and Occurrence of Ground Water

The major sources of recharge to the alluvial aquifer are flow from the shale and limestone bedrock that comprise the valley walls, induced flow through the banks of the Ohio River towards pumped wells, and precipitation that infiltrates to the water table. Not enough data were collected to calculate a water balance for the study area; however, flow from induced infiltration from the river and rainfall probably provide the largest amounts of water. Rorabaugh (1946, p. 35) indicated that about 6 inches of water (or 12 percent of annual precipitation) is added to the alluvial aquifer each year from precipitation infiltration in southwestern Jefferson County, Kentucky, about 5 miles northeast of the West Point area. Six inches of infiltration applied over the 5.7 square mile study area provides an estimated ground-water gain from precipitation of about 1.63 million gallons per day.

The water table in the alluvial aquifer near the HCWD #1 well field area is typically about 35 to 45 feet below land surface. Seasonal fluctuations in the water table could not be measured during the period of this study but they ranged from 2 to 4 feet in the alluvial aquifer near Louisville, Kentucky, about 10 to 15 miles northeast of the West Point area (Faust and Lyverse, 1987).

Flow of Ground Water

A map showing the configuration of water table in the alluvial aquifer on December 10, 1987, was constructed and used to determine the general directions of ground-water flow (fig. 3). The water-level contours indicate that ground-water movement is generally north to northwest towards the HCWD #1 and Fort Knox well fields and towards the Ohio River. The steep potentiometric gradients in the opposite direction between the Ohio River bank and the well fields indicate that pumped wells have reversed the natural flow gradient and is inducing water from the river into the well fields. Although this reversal is the result of pumping, similar reversals in flow direction



EXPLANATION

WELL FIELD

—381— WATER-TABLE CONTOUR--Shows altitude of water on December 10, 1987. Contour interval 1 foot. Datum is sea level

DIRECTION OF GROUND-WATER FLOW

DIRECTION OF SURFACE-WATER FLOW

381.2 OBSERVATION WELL AND ALTITUDE OF WATER TABLE

387.6 DOMESTIC WELL AND ALTITUDE OF WATER TABLE

Figure 3.--Configuration of the water table in the alluvial aquifer near West Point on December 10, 1987.

can occur temporarily under natural conditions when the river stage rises above the altitude of ground-water levels in the aquifer adjacent to the river.

WELL RECONNAISSANCE

Water Supply and Observation Wells

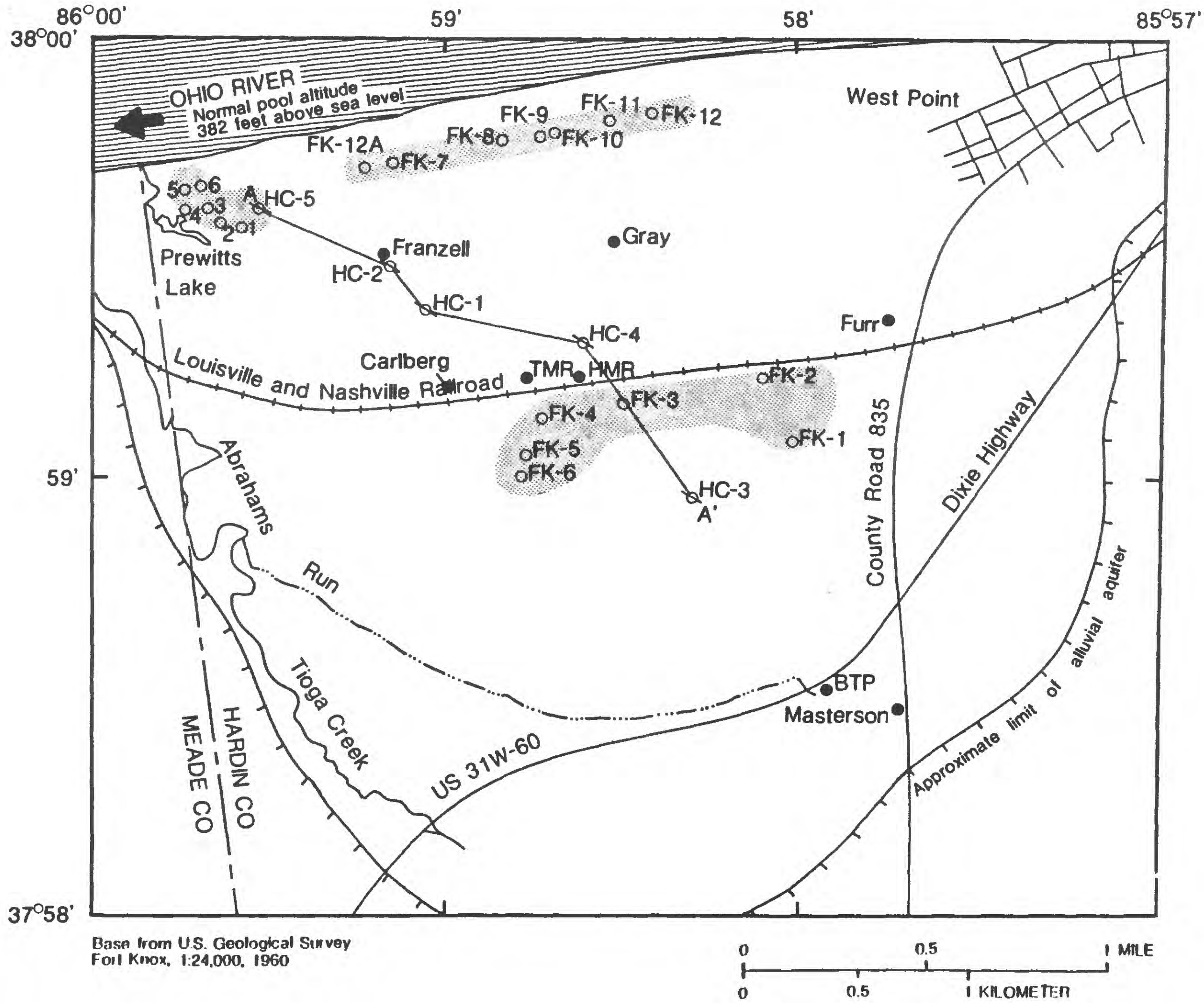
The HCWD #1 well field consists of six wells in the northwestern part of the study area. Well fields for the Fort Knox Military Reservation include a group of six wells south of the Louisville-Nashville Railroad track in the center of the study area and a line of seven wells along and parallel to the Ohio River (fig. 4). Ten observation wells were available in and near the well fields and 5 additional observation wells (HC-1 through HC-5) were drilled by the Survey to collect additional hydrogeologic data. Seven domestic wells were also available in the study area for data collection. Access to some of the wells was impossible or difficult and water levels were not measured in all the wells for the map in figure 3.

Oil and Gas Exploration Wells

Information on oil and gas wells was obtained through records and letters on file at the Louisville, Kentucky, office of the U.S. Geological Survey. The correspondence dates back to 1966 and is primarily between personnel from the U.S. Geological Survey, Louisville Gas and Electric Company (LG&E), and the Kentucky Division of Oil and Gas in the Department of Mines and Minerals.

Drillers' logs from several test wells in the study area have reported the presence of natural gas and oil in the alluvial aquifer; however, commercial exploration and development of natural gas has centered on the Muldraugh gas field located about 2 miles southwest of the study area. In the early 1950's this field was converted to a storage field for natural gas by LG&E. Underground service lines to Louisville, Kentucky, cross the study area from the southwest to the northeast. Current practice by LG&E at the Muldraugh storage field involves injecting natural gas into porous limestones beneath the New Albany Shale where it is stored for use at a later date. An assessment of the potential effect of pressurized natural gas storage in the limestones on upward movement of brine into the alluvial aquifer was beyond the scope of this study.

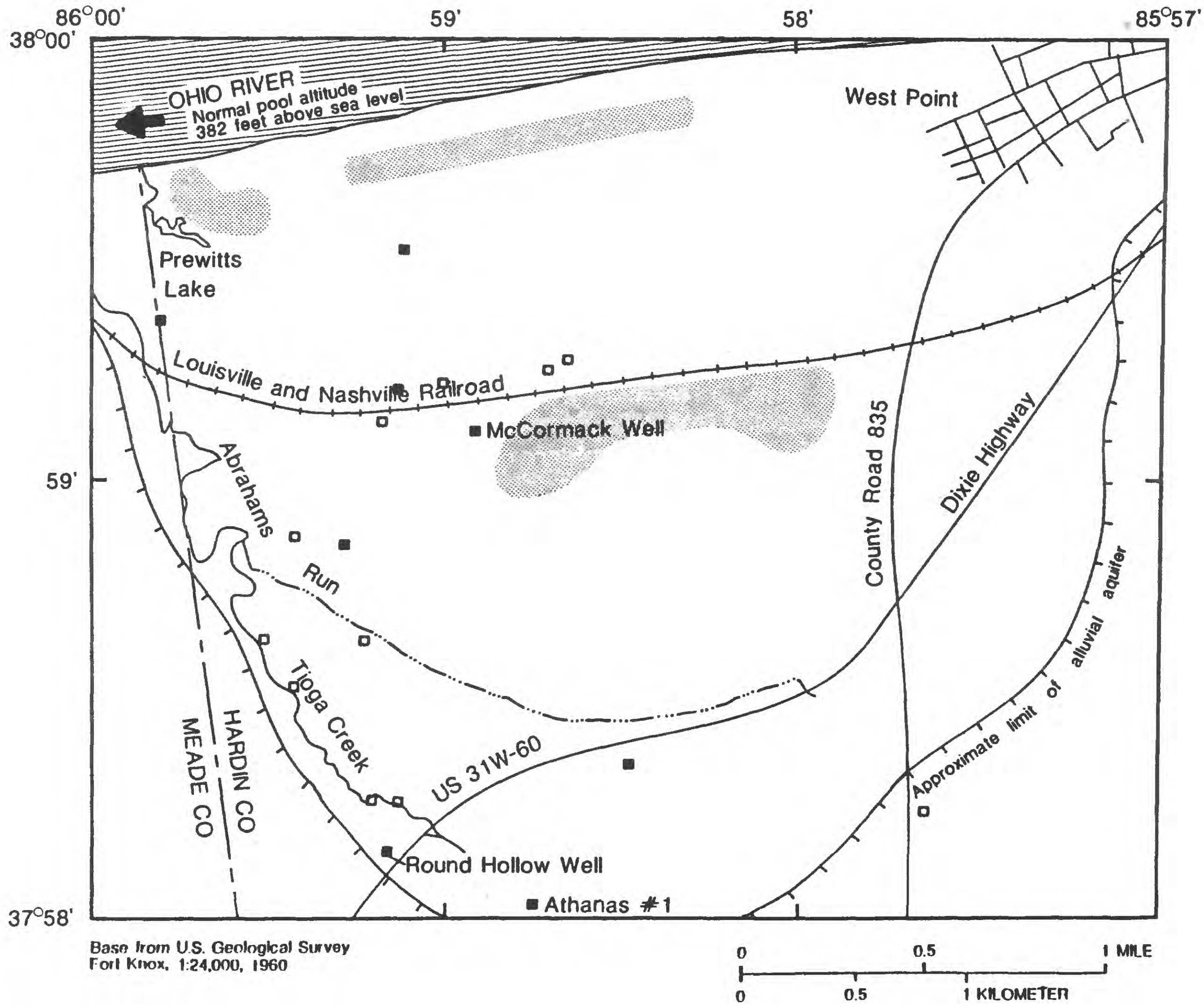
In the early to mid-1960's, LG&E investigated and documented the presence of oil and gas wells in the study area. LG&E personnel gathered information from 1918 and 1931 "farm maps," drillers' logs, and permits and were able to plot the approximate location of 20 oil and gas exploration wells (fig. 5). These wells ranged in total depth from 303 to 614 feet below land surface with the average depth being about 410 feet. According to drillers' logs, the majority of the wells were finished in limestones of Devonian and Silurian age. Twelve of the more detailed records indicated the occurrence of natural gas between 300 and 400 feet below land surface, pressurized "sulfur water" between 360 and 430 feet, and brine between 420 and 605 feet. Crude oil was observed at one site between 349 and 354 feet.



EXPLANATION

(shaded box)	WELL FIELD
A-A'	TRACE OF GEOLOGICAL SECTION--Section shown in figure 10
(arrow)	DIRECTION OF SURFACE-WATER FLOW
BTP ●	DOMESTIC SUPPLY WELL AND NAME
FK-3 ○	PUBLIC SUPPLY WELL AND NAME
HC-3	SURVEY OBSERVATION WELL AND NAME--See figure 3 for location of other observation wells

Figure 4.--Location of water wells in the alluvial aquifer near West Point.



EXPLANATION

WELL FIELD

DIRECTION OF SURFACE-WATER FLOW

■ OIL AND GAS TEST WELL--Location verified by Louisville Gas and Electric Company

□ OIL AND GAS TEST WELL--Location not verified by Louisville Gas and Electric Company

Figure 5.--Location of reported oil and gas test wells in the alluvial aquifer near West Point.

Field investigations conducted by LG&E personnel were able to verify the location of only 8 of the reported 20 wells. The remaining 12 wells were either considered destroyed or the files lacked sufficient data to determine their exact location in the field.

Three of the eight wells that LG&E personnel located were flowing "salt-sulfur" water at land surface. These wells were the Round Hollow well, the Athanas no. 1 well, and the McCormack well (fig. 5). All three wells had been reported as plugged when abandoned. LG&E set a series of plugs in the Round Hollow well in August 1966 and they planned to plug the Athanas no. 1. The records do not show if a plug was set in the Athanas no. 1 well, but they do show that the Round Hollow and Athanas no. 1 wells were flowing "salt-sulfur" water at land surface again in December of 1966. The McCormack well was reported flowing on October 10, 1969.

SURFACE GEOPHYSICAL SURVEY

Electromagnetic (EM) surface geophysical techniques provide information about the terrain conductivity of the subsurface (McNeill, 1980). High terrain-conductivity values are a result of subsurface materials, such as clay or shale, or high specific conductance ground water. When combined with additional geohydrologic data, such as data obtained from test drilling, this method provides a possible means for locating suspected ground-water contamination sites and for determining the lateral extent of contamination. In the alluvial aquifer near West Point, the presence of brine contamination was thought likely to cause high-terrain conductivity anomalies that could be measured with EM techniques.

The EM equipment selected for use in this study consists of an electronics module and two coils (transmitter and receiver) that are separated by a specified distance. When activated, the transmitter coil induces circular eddy current loops into the earth and the magnitude of each current loop is a function of subsurface conditions. The current flow produces a secondary magnetic field, but at a different phase or direction. This secondary phase can be detected at or above the ground surface with the electronics module, and it is linearly related to terrain conductivity (McNeill, 1980). The units of conductivity measurements are millimhos per meter (mmhos/m).

The effective depth at which terrain conductivities can be measured is a function of the orientation and spacing of the coils (McNeill, 1980). Two coil orientations were used: (1) the horizontal-dipole (coils up on edge and coplanar) and (2) vertical-dipole (coils flat on ground and coplanar) configurations. Effective depth of measurement for the horizontal dipole configuration is typically 0.75 times (or 75 percent of) the intercoil spacing and approximately 1.5 times the spacing for the vertical dipole configuration (McNeill, 1980, p. 6). The instrument is most responsive to near-surface conditions in the horizontal-dipole configuration, and to conditions at one half of the coil separation in the vertical-dipole configuration (McNeill, 1980, p. 7).

Collection of Electromagnetic Data

Terrain conductivity data for the study area were collected using a Geonics EM 34-3 XL transmitter and receiving system. Data were collected at intercoil spacings of 33, 66, and 131 feet at 81 stations in both the horizontal- and vertical-dipole configurations. These data were collected on a general grid-like pattern with 500-foot centers. Areas that could possibly be influenced by metallic (pipelines) or electrical (power lines) interference sources were avoided. Contoured apparent terrain-conductivity values at measured stations for the 131-foot spacing (horizontal- and vertical-dipole configurations) and the 66-foot spacing (vertical configuration) are shown in figures 6, 7, and 8. Effective depths for these spacings are approximately 98, 196, and 99 feet below ground surface, respectively. Shallower depths of electromagnetic penetration are not shown because the effective measured depth was at or above the water table.

Electromagnetic Data Analysis

Terrain conductivity values in the alluvial aquifer for the effective depths of 98 and 99 feet range from 10 to 50 mmhos/m. The "bulls-eyes" shown in figures 6, 7, and 8 indicate that two distinct areas of high conductivity became increasingly apparent in direct proportion to effective depth of penetration. (This increase was substantiated by test drilling and will be discussed in the next section). Due to greater effective depth of penetration (196 feet), electromagnetic responses from relatively conductive shales that underlie the alluvial deposits probably influenced the terrain conductivity values observed at the effective depth of 196 feet (fig. 8). A vertically downward distribution of increasing terrain conductivity is to be expected if the cause for the high conductivity is the result of an intrusion of brine into the less dense fresh water of the alluvial aquifer.

As mentioned earlier, high terrain-conductivity values may result from subsurface materials such as clay or shale, high specific conductance ground water, or from abandoned metal well casing left in the aquifer in exploratory oil and gas wells. Drilling in the study area revealed that thin beds or lenses of clays exist in the alluvial aquifer, and as a result, these beds or lenses may cause higher terrain-conductivity values than would exist without them. The higher values that may have resulted were considered insignificant to overall interpretation of the terrain-conductivity values because, (1) the clay lenses or beds are present throughout the alluvial aquifer and therefore their contribution to high readings at specific sites was probably minimal, and (2) significantly higher terrain-conductivity values that resulted from the entry of brine into the alluvial aquifer probably mask the less significant effect of the clay lenses or beds.

Metal casing from one abandoned well used previously as a domestic gas supply well (near test well HC-4, fig. 4) was observed at ground surface during the EM survey. The casing was assumed to extend throughout the entire thickness of the alluvial aquifer (approximately 100 feet). As a result of this casing, terrain-conductivity readings taken near the well may have been slightly elevated. Because the casing was only 4 inches in diameter and test drilling later confirmed the presence of high chlorides (resulting in high specific conductance ground water) in the alluvial aquifer near this well, the overall effect of the metal casing on terrain-conductivity readings and interpretations was considered minimal.

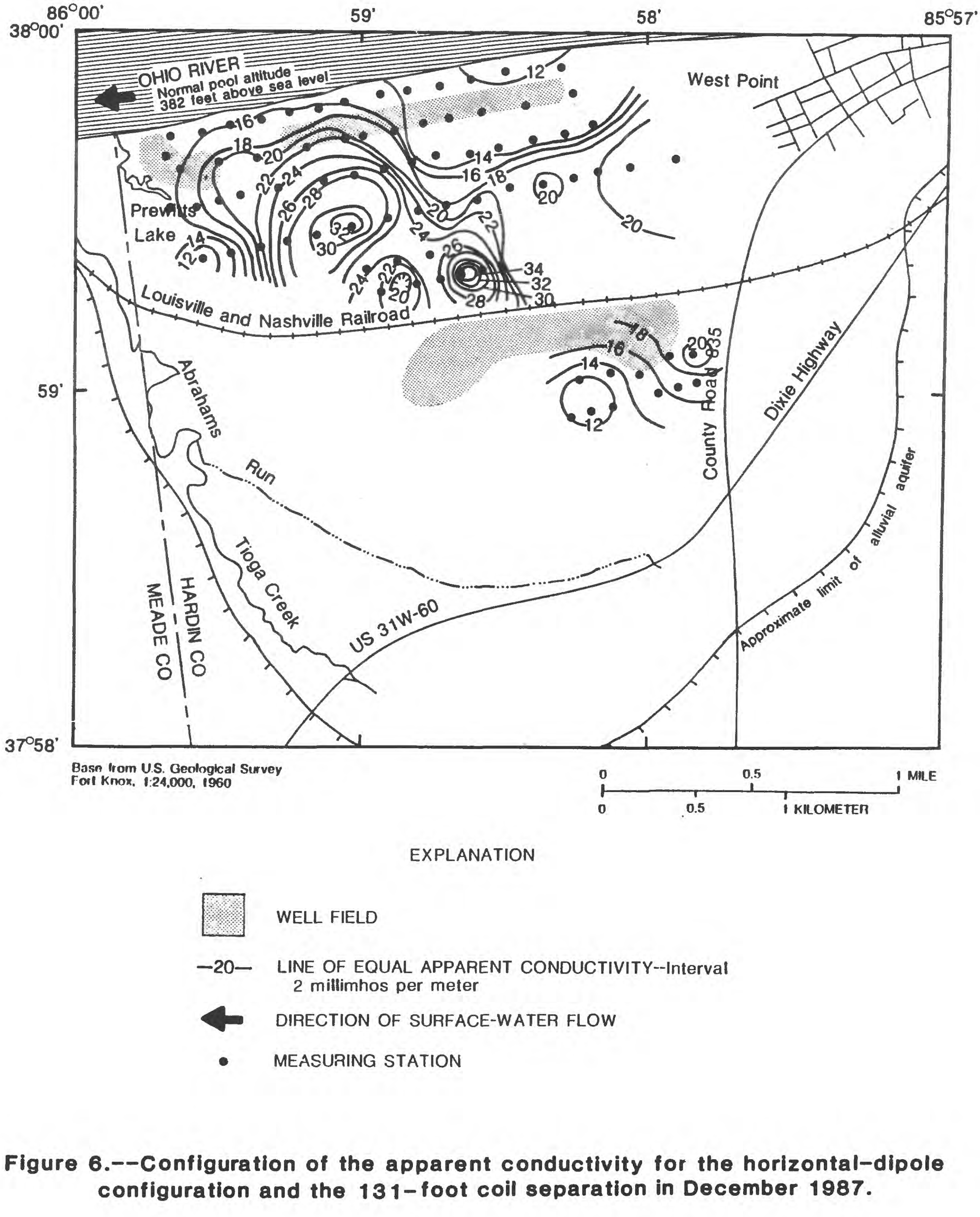
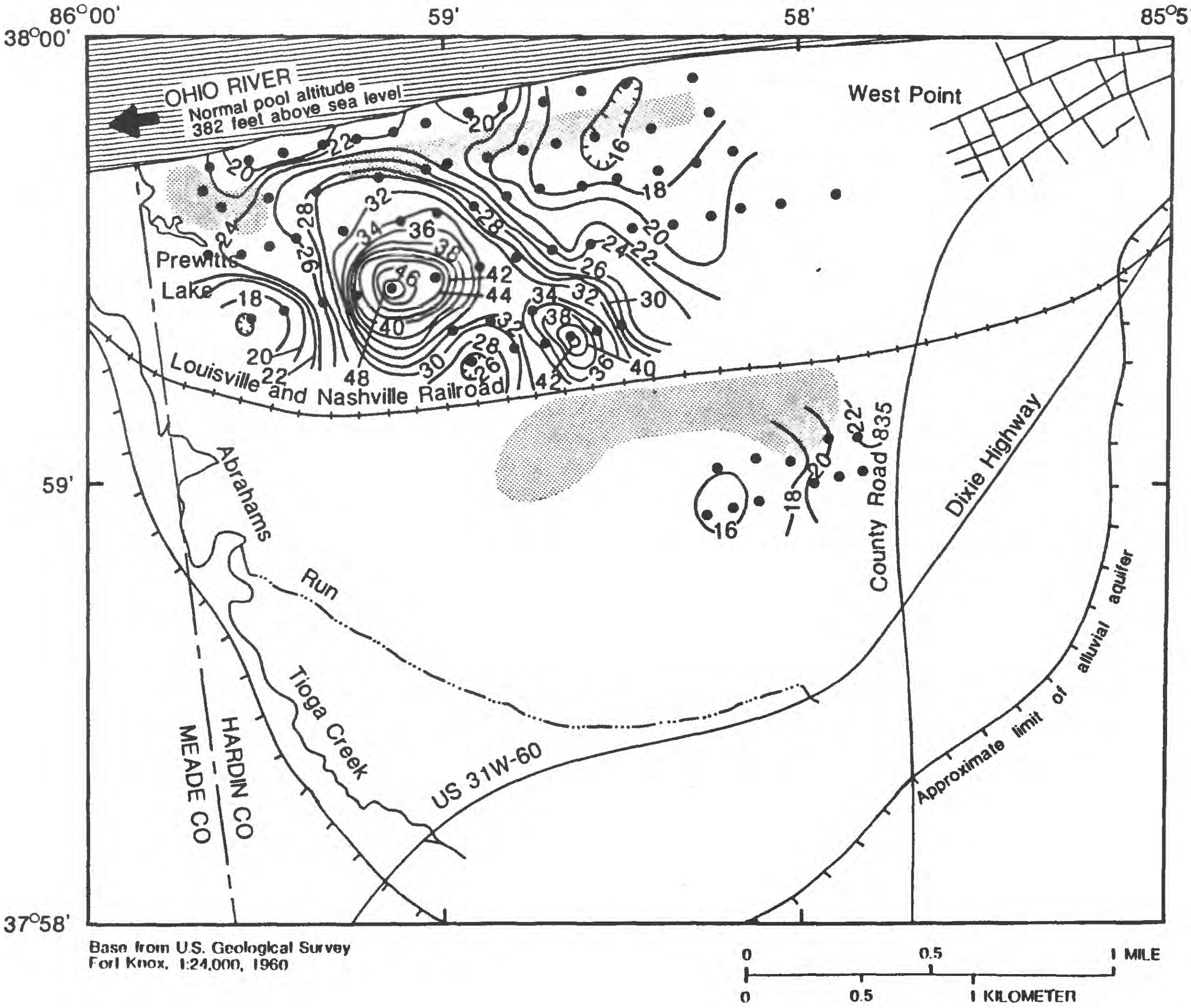


Figure 6.--Configuration of the apparent conductivity for the horizontal-dipole configuration and the 131-foot coil separation in December 1987.



EXPLANATION

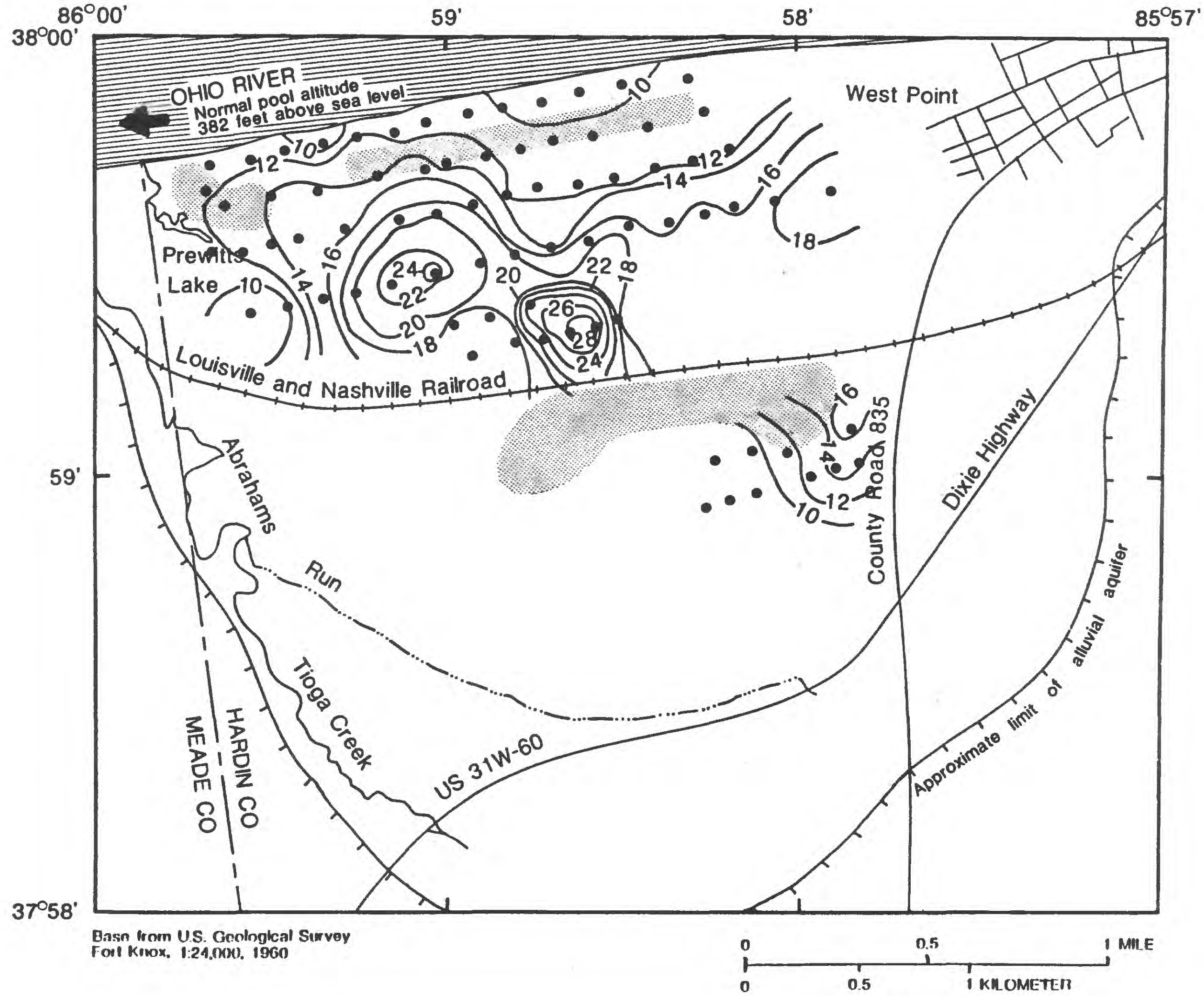
WELL FIELD

—20— LINE OF EQUAL APPARENT CONDUCTIVITY--Interval 2 millimhos per meter

DIRECTION OF SURFACE-WATER FLOW

• MEASURING STATION

Figure 7.--Configuration of the apparent conductivity for the vertical-dipole configuration and the 131-foot coil separation in December 1987.



EXPLANATION

WELL FIELD

—20— LINE OF EQUAL APPARENT CONDUCTIVITY--Interval 2 millimhos per meter

DIRECTION OF SURFACE-WATER FLOW

• MEASURING STATION

Figure 8.--Configuration of the apparent conductivity for the vertical-dipole configuration and the 66-foot coil separation in December 1987.

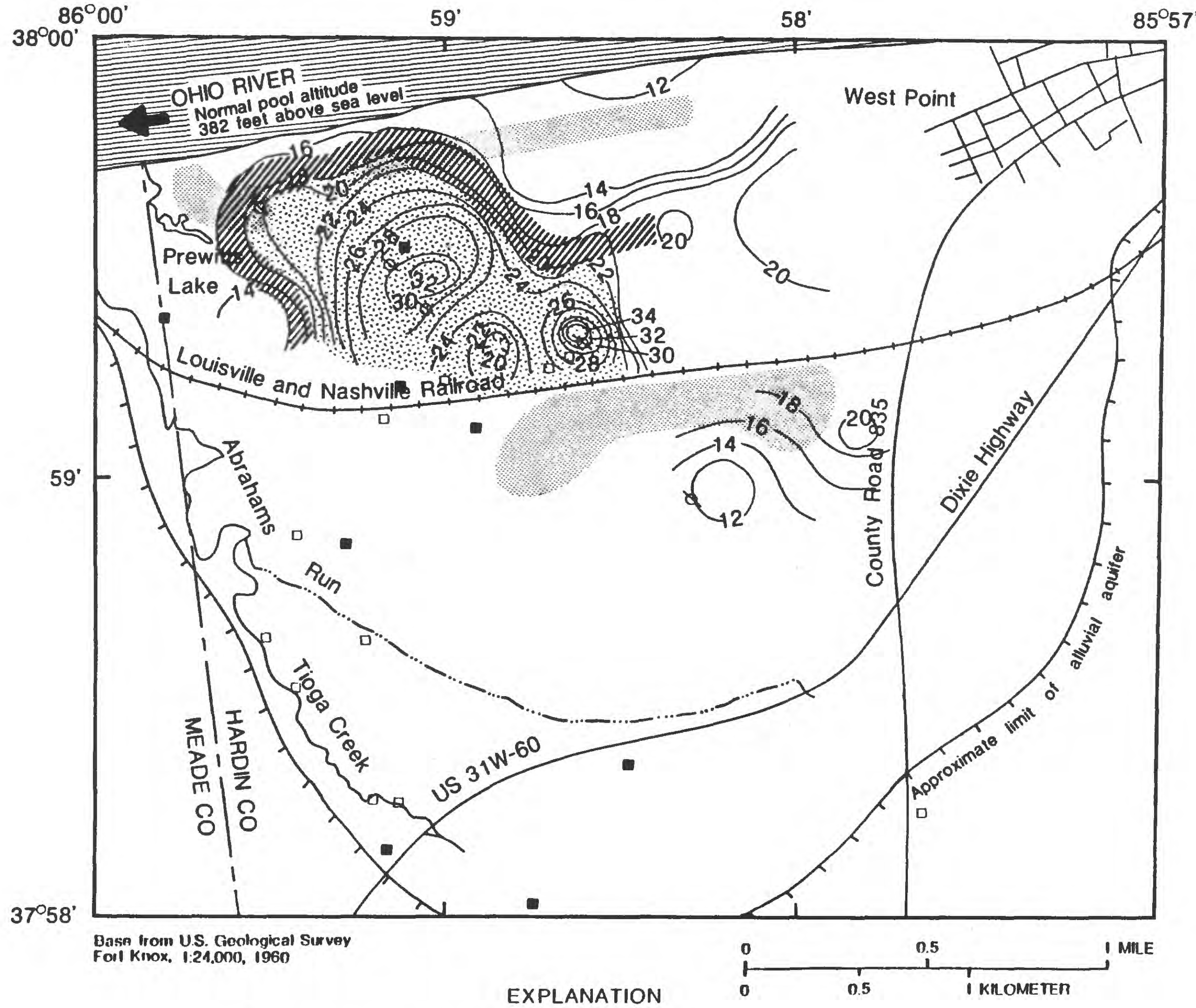
A range of apparent conductivity values shown in figure 6, collected with an effective depth of measurement of 98 feet which approximates the thickness of the alluvial deposit, can be interpreted in the context of the geohydrologic setting as follows:

Apparent conductivity in millimhos per meter	Geohydrologic setting
<17	"Uncontaminated Areas"; ground water probably not contaminated with brine or other inorganic constituents.
18-20	"Possibly Contaminated Area"; conductive sediments or contaminated ground water exist.
>21	"Presumably Contaminated Areas"; ground water at some depth is probably contaminated by brine.

In general, the study area can be divided into sub-areas that contain water that is uncontaminated, possibly contaminated, and presumably contaminated. "Contaminated water," in this context, is based on concentrations of chloride of more than 250 mg/L. Chloride was chosen as an indicator ion for brine contamination because the higher the concentration of chloride in ground water, the greater is the presumed brine contamination. The sub-areas mentioned above are approximately delineated in figure 9 by shading apparent terrain-conductivity contours described above as approximate boundaries. The contaminated areas typically surround a known or potential ground-water contamination source, such as abandoned oil and gas exploration wells, which are also shown in figure 9.

TEST DRILLING AND WATER QUALITY

Five 7 1/4-inch diameter test wells were drilled in the alluvial aquifer to provide geologic data, water-level data, information on the vertical and areal distribution of chloride, and a verification of terrain-conductivity interpretations. Locations of the test wells are shown in figure 4. Drilling sites were selected based on proximity to the HCWD #1 well field, terrain conductivity measurements, and proximity to known or reported abandoned oil and gas exploration wells. Two test holes, HC-1 and HC-4, were located near reported exploration wells which also corresponded to the areas of highest terrain conductivity. Test wells HC-2 and HC-5 were drilled on a line between the HCWD #1 well field and areas of presumed ground-water contamination in order to investigate the spatial changes in contaminant concentration that occur with distance from the presumed contaminant source. Well HC-3 was drilled in an area upgradient from all the other wells. Water quality at this well was considered representative of background conditions. HC-1, -4, and -5 were finished as 1 1/2-inch diameter monitoring wells, HC-2 was drilled and abandoned because it was adjacent to a previously drilled well that can provide long-term water-level measurement data, and HC-3 was abandoned after



EXPLANATION

WELL FIELD

AREA PRESUMABLY CONTAMINATED AT SOME DEPTH BY BRINE

AREA POSSIBLY CONTAMINATED AT SOME DEPTH BY BRINE

—20— LINE OF EQUAL APPARENT CONDUCTIVITY--Interval 2 millimhos per meter

DIRECTION OF SURFACE-WATER FLOW

■ OIL AND GAS TEST WELL--Location verified by Louisville Gas and Electric Company

□ OIL AND GAS TEST WELL--Location not verified by Louisville Gas and Electric Company

SURVEY OBSERVATION WELL

Figure 9.--Areas of possible brine contamination in the alluvial aquifer near West Point in December 1987.

drilling difficulties prevented completion. HC-2 and HC-3 were abandoned by filling the holes with drill cuttings to the original land surface as stipulated in abandonment procedures. Records of the test wells are on file in the Louisville, Kentucky, office of the U.S. Geological Survey.

In order to determine the extent and magnitude of chloride contamination in the alluvial aquifer, water samples were taken with a submersible pump at approximately 10-foot intervals below the water table. These samples were taken as drilling progressed by lowering the pump inside the hollow stem augers until the pump was adjacent to a slotted auger flight that allowed the entry of water. The water level inside the flights was allowed to stabilize at which time 2 to 3 borehole volumes of water were evacuated prior to collecting a sample. When sampling was completed at one zone, drilling proceeded to a lower depth and the procedure was repeated. By using this technique, a vertical distribution of chloride concentrations was developed based on sampling at the 10-foot intervals. At two test wells (HC-2 and HC-4), samples were collected at four depths for comprehensive water-quality analyses. An electromagnetic conductivity profile between test wells HC-5 and HC-3 is shown in figure 10A. Values shown in the profile were obtained using a coil spacing of 131 feet, in the horizontal-dipole configuration.

The generalized geology, altitude of the water table in late October and early November 1987, and the vertical distribution of chloride in the test drilling area are shown in the cross section in figure 10B.

The apparent coning of chloride concentrations near test wells HC-1 and HC-4 (fig. 10B) is assumed to be the result of upward movement of diluted brine waters originating from sources below the shale bedrock. A review of logs from oil and gas exploration wells drilled prior to the 1970's indicated that most exploration wells were drilled to depths greater than 400 feet below land surface. The entry of brine water into the drill hole was noted on occasion by drillers. In fact, local residents report that it was not unusual to observe saltwater flowing from some of these wells. Although not quantitative in nature, these reports indicate that the brine at depth is probably under confined conditions and will readily move upward when the confined aquifers are penetrated. Residents also report that plugging of several abandoned exploration artesian wells consisted of jamming telephone poles or something of similar diameter into the well casing and sealing the well with cement. This procedure was probably not effective in limiting the migration of brine into the lower parts of the alluvial aquifer. The exploration well near well HC-1 was reported to be sealed only near land surface and no known attempt was made to seal the exploration well near well HC-4.

The elongation of the plume of higher chloride concentrations toward the north is probably caused by the northerly flow of ground water towards the HCWD #1 well field and the Ohio River (fig. 10B). Another source of brine may be present in this area, but was not explicitly detected by the EM measurements. The decrease in chloride concentrations further north probably indicates a progressive dilution of the brine as it mixes with fresh water in the alluvial aquifer.

Chemical differences in water at different depths in wells HC-1 and HC-4 are shown on the quadrilinear diagram in figure 11. Quadrilinear diagrams are

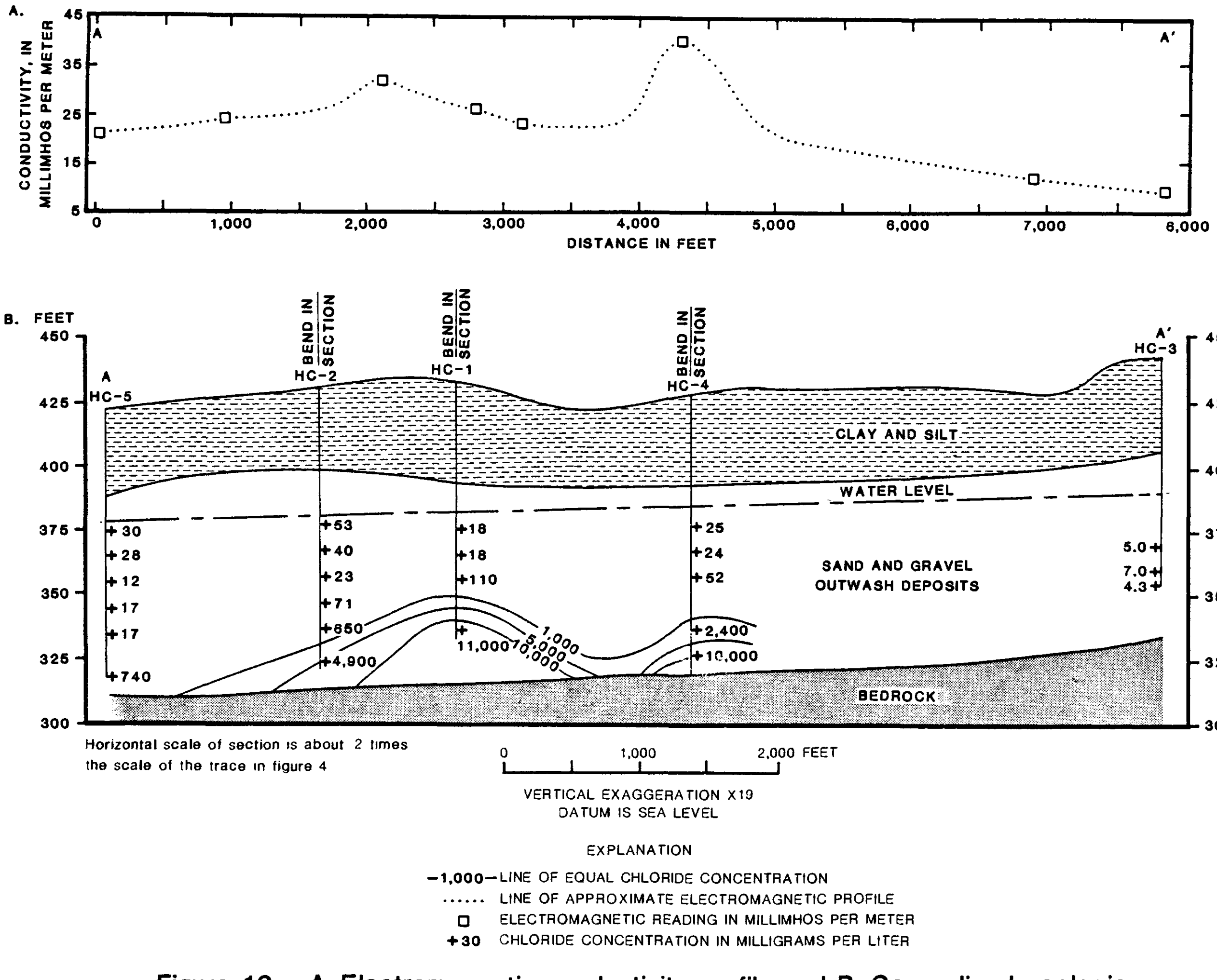
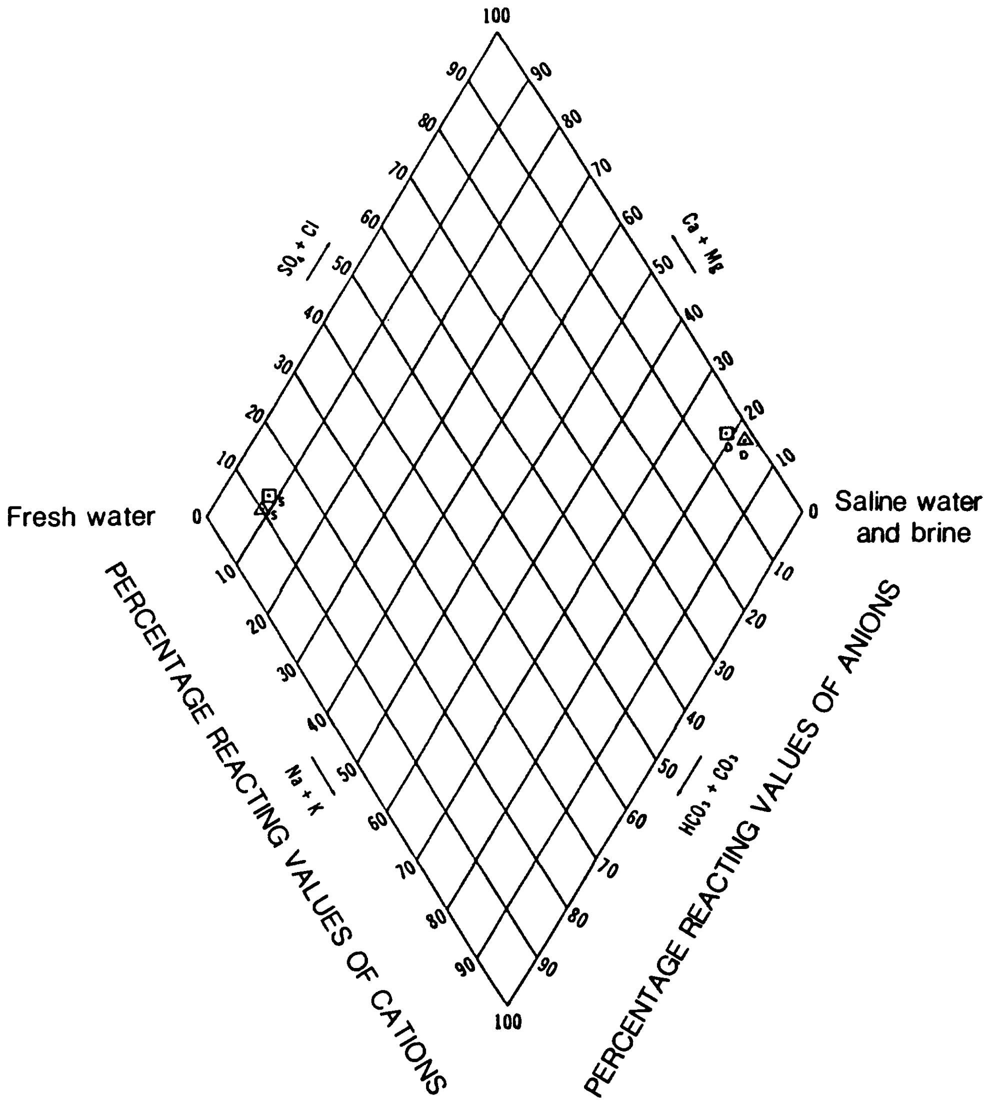


Figure 10.--A. Electromagnetic conductivity profile and B. Generalized geologic section showing Survey test wells, vertical chloride concentrations, and altitude of water level on December 10, 1987. (See figure 4 for location of wells.)



EXPLANATION

WATER SAMPLE FROM TEST WELLS
IN FEET BELOW LAND SURFACE

△S HC-4 at 60 feet

△D HC-4 at 100 feet

□S HC-2 at 72 feet

□D HC-2 at 104 feet

Figure 11.--Quadrilinear plots of analyses of water samples from test wells HC-2 and HC-4.

a modification of tri-linear diagrams as described by Hem (1970), and are a way to illustrate ground-water quality or in this case, changes in water quality with depth. Each point on the quadrilinear diagram represents one complete analysis containing measurements of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride ions.

The quadrilinear diagram shows that water in the alluvial aquifer for these two wells can be classified as fresh water (primarily calcium bicarbonate) at shallow depths (60-72 feet), changing to very saline water or brine (sodium chloride) at depths (100-104 feet) near the base of the alluvium. An indication of mixing or transition between fresh and saline water was not obvious from these samples but presumably occurs somewhere in between these depths, probably in the lower one third of the alluvial aquifer as the cross section showing chloride concentrations in figure 10B indicates. Accurate rates for dilution of the brine for measured constituents are difficult to predict because a sample of the brine was not obtained from the suspected sources (abandoned exploration wells) before it had become mixed with water in the alluvium.

EVALUATION OF GROUND-WATER CONTAMINATION

Chloride

Because concentrations of chloride in excess of regulatory limits have caused the abandonment of several wells at the HCWD #1 well field, samples for chloride analysis were collected from all accessible wells identified from the well inventory. The secondary maximum contaminant concentration for chloride for public water supplies is 250 mg/L (U.S. Environmental Protection Agency, 1986a). Sampling was conducted during the period October 14-20, 1987, and all sampled wells were screened in the alluvial aquifer. Results of the analyses are listed in table 1 and confirm the presence of high concentrations of chloride in wells FK-7, HCWD #1 (wells no. 1 and no. 3), and the Franzell well (fig. 4). The Franzell well is near the well field and downgradient from several abandoned oil and gas wells (fig. 5). Comparison of the chloride concentration in samples collected in July 1987 by personnel with the HCWD #1 with those of samples collected in October 1987 for this study shows an increase from 250 to 530 mg/L in HCWD #1, well no. 1, and from 170 to 210 mg/L in HCWD #1, well no. 3. The concentration of chloride in HCWD #1, well no. 2, was 320 mg/L in July 1987. However, this well could not be sampled in October because the pump was inoperable. The chloride concentration in water from HCWD #1, well no. 4, the well thought to be farthest from the suspected sources of brine, remained relatively constant at about 35 mg/L during the same period. According to reports from Fort Knox, FK-7 is seldom used because of its chloride content. This well is in an area where Fort Knox had previously abandoned several wells because of high chloride concentrations.

Also included in table 1 are the results of chloride analyses of water samples collected during a 24-hour aquifer test conducted at HCWD #1, well no. 6, a newly drilled supply well near HCWD #1, well no. 1. These samples are listed as PW-1, PW-2, and PW-3, and were collected by HCWD #1's drilling contractor at the beginning, middle, and end of the test, respectively.

Table 1.--Chloride concentrations and specific conductance in water from wells tapping the alluvial aquifer near West Point, Kentucky, October 1987

Well[1]	Specific Conductance (microsiemens per centimeter)	Chloride (milligrams per liter)
FK-1	581	6.5
FK-2	628	7.3
FK-3	610	5.4
FK-4	610	8.5
FK-5	496	9.2
FK-6	630	46
FK-7	1,420	290
FK-8	540	33
FK-10	484	13
FK-11	540	12
FK-12	420	16
HCWD #1, well no. 1	2,200	530
HCWD #1, well no. 3	1,080	210
HCWD #1, well no. 4	565	34
BTP	692	9.2
HMR	592	8.1
TMR	520	33
Carlberg	603	29
Gray	517	8.8
Masterson	598	17
Franzell	18,080	6,600
Furr	700	20
HCWD #1, well no. 6		
PW-1	470	42
PW-2	405	27
PW-3	414	26

[1]Well designations from figure 4.

Oil and Grease

Because oil and grease has occurred in concentrations sufficient to impede the operation of sand filters at the water treatment plant for HCWD #1, concentrations for oil and grease were also determined for water samples collected in October 1987. These were the same wells that were sampled for chloride analysis (fig. 4 and table 1). None of the water samples contained oil and grease concentrations in excess of the minimum detectable limit (1 mg/L). On the basis of these results, oil and grease is not considered a contaminant in these samples.

Radioactivity

Gross-alpha radioactivity was determined in samples from 12 wells (table 2). Because of high concentrations of total dissolved solids in several samples, the minimum detectable limit for the analysis of gross-alpha radioactivity was relatively high (particularly for well FK-3 and the Gray well). Still, results of these analyses show that gross-alpha radioactivity was below the maximum contaminant level of 15 picocuries per liter (pC_1/L) for public water supplies as specified by the U.S. Environmental Protection Agency (1986b). Although one supply-well sample collected by HCWD #1 in 1986 had been reported to contain an elevated level of gross-alpha radioactivity, none of the samples analyzed in this study had a gross-alpha particle radioactivity above the minimum detection limits. Therefore, gross-alpha radioactivity was not considered a contaminant of significance.

Table 2.--Gross-alpha particle activity of water from wells in the alluvial aquifer near West Point, Kentucky, October 1987

Well[1]	Gross-alpha radioactivity[2] (soluble) (picocurie per liter)
HCWD #1, well no. 1	< 5.2
HDWD #1, well no. 3	< 4.8
Carlberg	< 3.0
Gray	<15
BTP	< 2.6
FK-1	< 3.2
FK-3	<15
FK-5	< 1.5
FK-6	< 3.3
FK-7	< 3.2
FK-8	< 4.5
FK-12	< 6.0

[1]Well designations from figure 4

[2]Values represent the minimum detectable limits for the samples.

POTENTIAL FOR CONTAMINATION OF ADDITIONAL WATER-SUPPLY WELLS AND ADDITIONAL DATA NEEDS

The following discussion of the potential for additional contamination of the HCWD #1 well field is limited to a discussion of chloride contamination. The possibility of chloride contamination reaching currently used HCWD #1 supply wells is of major importance to the water district. Additional contamination of water-supply wells is a possibility because the natural flow gradient in the alluvial aquifer (fig. 3) is from the areas of high chloride concentration to the well fields along the river and the gradient may be increased by pumping in the well fields. Current well field practices of switching withdrawals between several production wells on a day-to-day basis probably represents an efficient means of minimizing chloride contamination. This practice slows the expansion of the cone of depression (zone of drawdown) around a production well. A cone of depression (if allowed to expand) could encompass areas of the aquifer that have excessive concentrations of chlorides. Because the effective recharge area for a production well is related to the area of the cone of depression surrounding it, the longer a given well is pumped, the larger the area of recharge must be in order to supply water to the well. Pumping a well for prolonged periods of time increases the chance for chlorides to reach the well from greater distances.

Future development and efficient use of the ground-water resources in the West Point area requires that care be taken in well-field design and construction. Proper well location and spacing should be determined as a function of the alluvial aquifer's local hydrologic characteristics. Local aquifer characteristics such as width, saturated thickness, hydraulic conductivity, storage, and the hydraulic conductivity of the river bank all control, to some extent, the maximum rate of withdrawal of water from the aquifer. Previous investigators (Rorabaugh, 1956, Grubb, 1974) have shown that large sustained rates of withdrawal of water from alluvial aquifers, such as the one near West Point, are possible only because of induced infiltration from the Ohio River. If this source of water were not available as recharge to the wells, water in storage in the alluvial aquifer would be substantially decreased or depleted.

Digital flow modeling may be used to test new pumping scenarios in the HCWD #1 well field and to provide estimates of local hydrologic characteristics of the alluvial aquifer. Once a flow model has been compiled and calibrated for the well field area, the model can be used as a management tool to aid in the design of new well fields, or in the addition of new wells to the existing well field. Because flow models are best calibrated on existing field data, additional water-level data would be required for more refined water-table maps. This would require the installation of more observation wells than currently exist in the well field area. These wells could also be used to obtain samples to monitor water quality in the aquifer.

If enough data were collected, particularly near the source of the brine leakage, a transport model could possibly be developed for the purpose of tracking the movement of chlorides in the well field area. Various pumping scenarios could be tested in order to evaluate the effects of long term pumping at current or proposed well locations or to test the feasibility of an "interceptor" well that would be pumped solely to divert contaminated water from the public supply wells.

Other data needs of aquifer management schemes might include periodic use of surface geophysical methods, such as the EM methods used in this study, to monitor the transport of chlorides through the alluvial aquifer. The EM method could be used to determine significant changes in apparent terrain conductivity due to new or increased concentrations of chloride in the ground water from one time period to the next. EM methods might provide a relatively inexpensive means for monitoring chloride movement.

SUMMARY AND CONCLUSIONS

The extent of brine contamination of the alluvial aquifer near West Point, Kentucky, in 1987 was evaluated and qualitatively described. The source of this contamination is probably upward movement of brines from improperly abandoned oil and natural gas test wells. Chloride is the brine constituent of most concern to Public Health Authorities.

The approximate extent of brine contamination was determined using electromagnetic (EM) terrain-conductivity observations. Test drilling and water sampling were used to verify several of the high chloride areas identified by terrain-conductivity anomalies. Contamination appears to be widespread in the northeastern part of the alluvial aquifer and concentrated in areas proximate to abandoned oil and natural gas test wells. Recently, several Hardin County and Fort Knox supply wells were abandoned due to unacceptable concentrations of chloride. Brine concentrations apparently diminish down flow gradients away from source areas because of dilution of brines with fresh water in the alluvial aquifer.

Water quality data collected for this study indicated little or no contamination to water supply wells has occurred from oil and grease and gross-alpha radioactivity. Concentrations of chloride up to 11,000 mg/L were observed in wells near abandoned oil and natural gas test wells.

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