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GROUND - WATER TEMPERATURE OF THE WYOMING QUADRANGLE IN CENTRAL DELAWARE, WITH APPLICATION TO GROUND-WATER-SOURCE HEAT PUMPS

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Water-Resources Investigations Report 82-53

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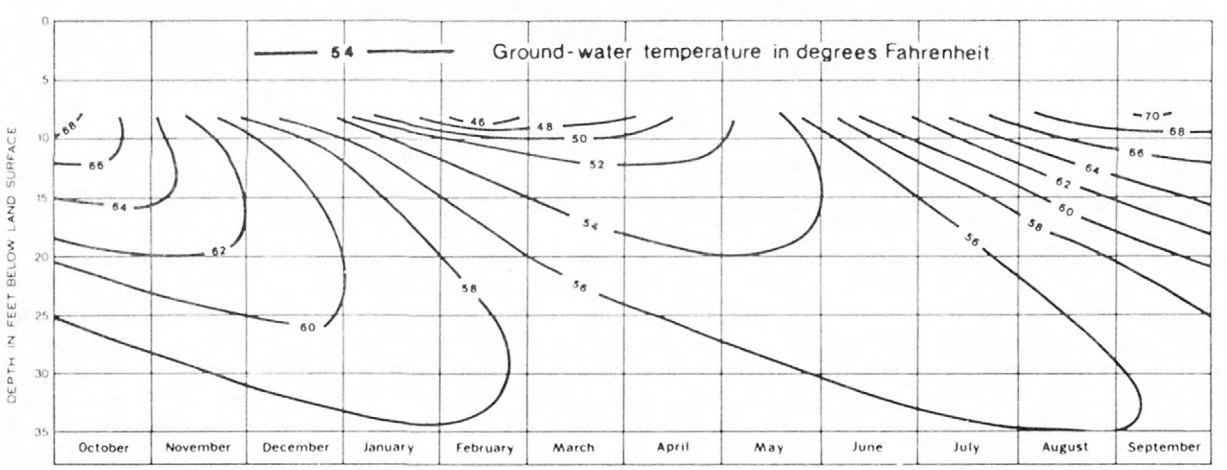

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GROUND - WATER TEMPERATURE OF THE WYOMING QUADRANGLE IN CENTRAL DELAWARE, WITH APPLICATION TO GROUND-WATER-SOURCE HEAT PUMPS

by Arthur L. Hodges, Jr.

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 82-53

September 1982

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

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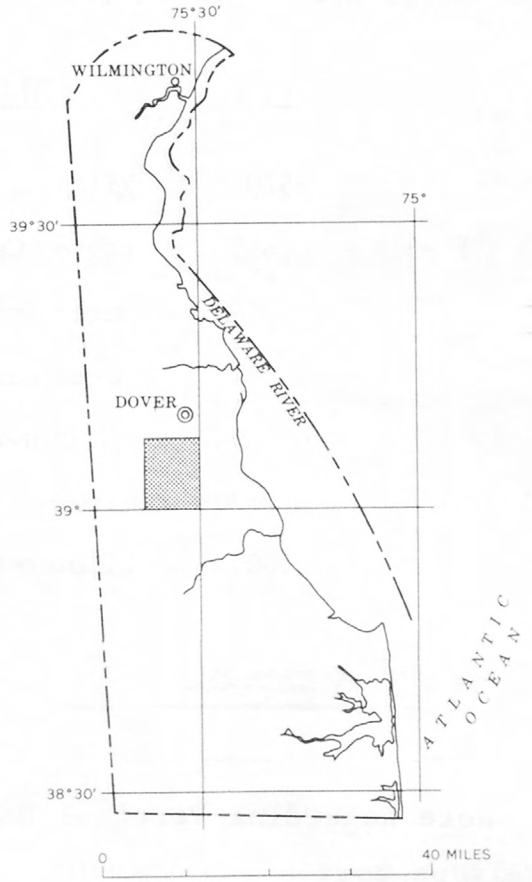
CONVERSION TABLE

Factors for converting the units of measurement used in this report to metric units are shown in the following table.

MULTIPLY	BY	TO OBTAIN
BTU	2520	kilogram - calories
degree Fahrenheit (°F) (°F -32) x	0.555	degree Celsius (°C)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
gallon per minute (gal/min)	0.06308	liters per second (l/s)
mile (mi)	1.609	kilometer (km)

Note Regarding Vertical Datum

The National Geodetic Vertical Datum of 1929, the reference surface to which relief features and altitude data are related, and formerly called mean sea level, is referred to as sea level in this report.



Index map of Delaware showing
location of the Wyoming quadrangle.

GROUND-WATER TEMPERATURE OF THE WYOMING QUADRANGLE IN CENTRAL DELAWARE, WITH APPLICATION TO GROUND-WATER-SOURCE HEAT PUMPS

by Arthur L. Hodges, Jr.

ABSTRACT

Ground-water temperature was measured during a one-year period (1980-81) in 20 wells in the Wyoming quadrangle in central Delaware. Data from thermistors set at fixed depths in two wells were collected twice each week, and vertical temperature profiles of the remaining 18 wells were made monthly. Ground-water temperature at 8 feet below land surface in well Jc55-1 ranged from 45.0°F in February to 70.1°F in September. Temperature at 35 feet below land surface in the same well reached a minimum of 56.0°F in August, and a maximum of 57.8°F in February. Average annual temperature of ground water at 25 feet below land surface in all wells ranged from 54.6°F to 57.8°F. Variations of average temperature probably reflect the presence or absence of forestation in the recharge areas of the wells. Ground-water-source heat pumps supplied with water from wells 30 or more feet below land surface will operate more efficiently in both heating and cooling modes than those supplied with water from shallower depths.

INTRODUCTION

Heat extracted from ground water by a heat pump is an energy-efficient method of space heating. To design a system that utilizes ground water as an energy resource, however, the availability, temperature, rate of movement and quality of the water must be known. The purpose of this study was to determine these factors in central Delaware. Funding for this study was provided by the Office of Earth Sciences Applications (OESA), U.S. Department of the Interior.

Location of the Study Area

The Wyoming quadrangle in central Delaware (fig. 1) was selected for study because the ground water divide between drainage to the Atlantic Ocean and Chesapeake Bay occurs in the western part of the quadrangle, and a tidal stream drains the northwestern part. Thus, both extremes of hydrologic environment on the coastal plain of the Delmarva Peninsula are available for study in this quadrangle.

GEOHYDROLOGY OF THE WYOMING QUADRANGLE

The Wyoming quadrangle is underlain by alternating layers of sand, silt and clay that range in total thickness from about 2,900 feet to 3,700 feet (Marine and Rasmussen, 1955). Except for the top few feet, this material is saturated with water. The deepest currently used source of water in the quadrangle is the Piney Point aquifer, the top of which is 300 to 650 feet below sea level (fig. 2). The top of the Cheswold aquifer ranges between 100 and 350 feet, and the Frederica aquifer between 0 and 150 feet below sea level (Sundstrom and Pickett, 1968). The shallowest source of water is the unconfined aquifer, which extends from land surface to as much as 26 feet below sea level and has a saturated thickness of 24 to 70 feet (Johnston, 1973). These aquifers are the source of all municipal and private water supplies in the area.

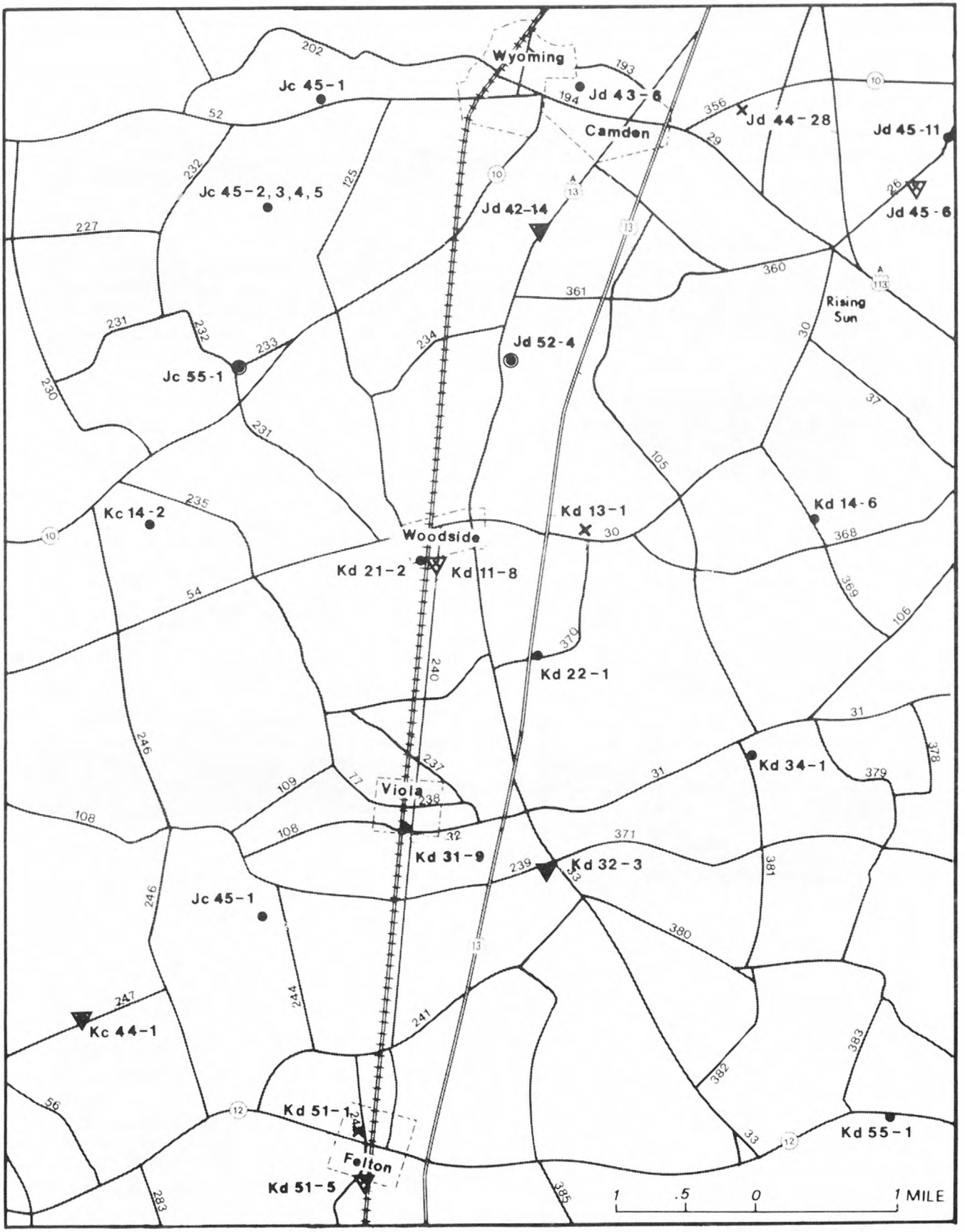


Figure 1. Location of study area and test wells.

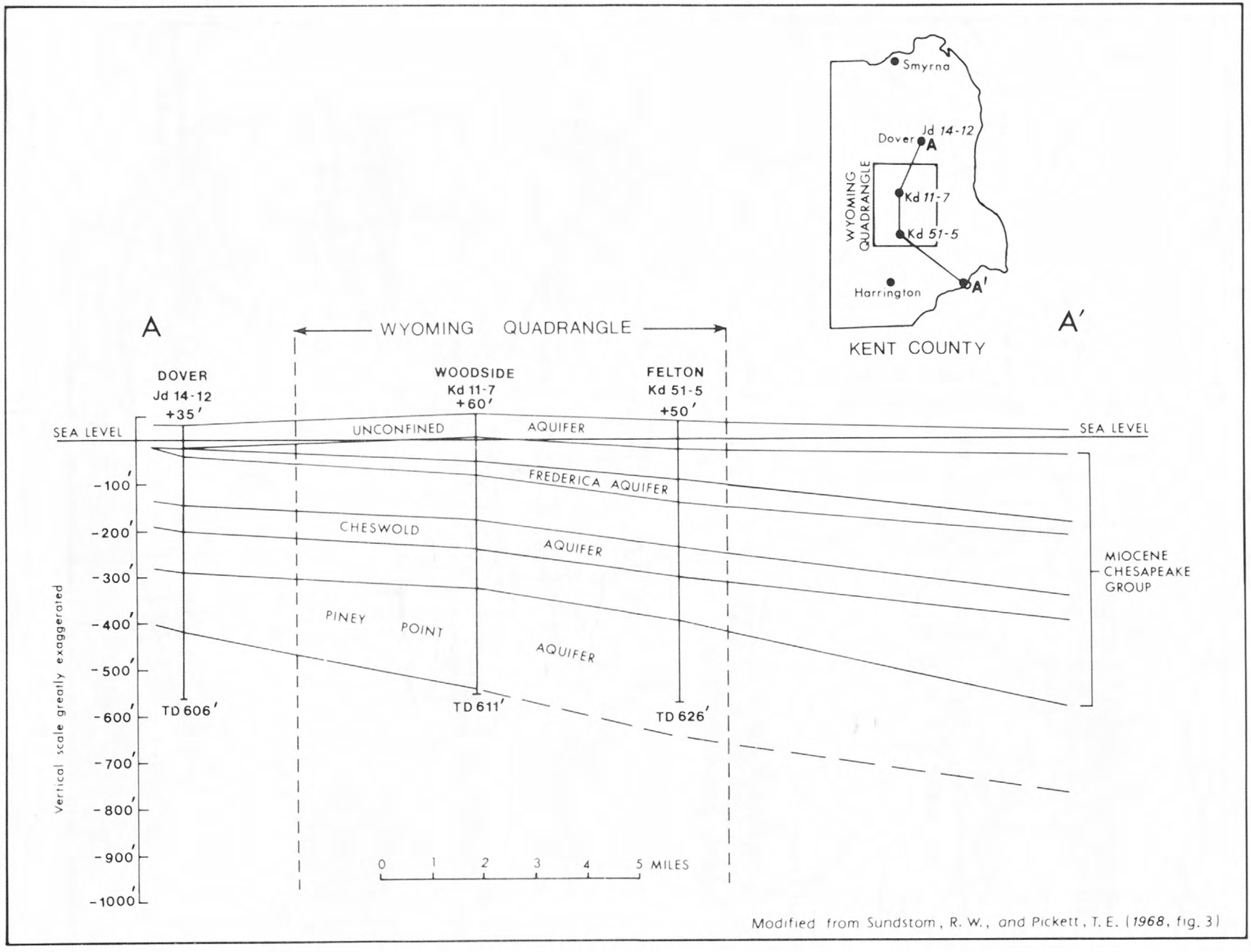


Figure 2. Geohydrologic section of the Wyoming quadrangle area.

Water levels in the aquifers range from more than 80 feet below sea level up to land surface. Leahy (1979, fig. 7) reported that the 1975 water level in the Piney Point aquifer ranged from 80 to 50 feet below sea level between Camden and Felton. Water levels shown in the same report for the Cheswold aquifer in 1975 ranged from sea level to about 30 feet above sea level between the same towns. No water-level data are available for the Frederica aquifer in the Wyoming quadrangle; however, testing done for the State of Delaware at Sandtown, 8 miles west of Felton, showed water levels in the Frederica aquifer to be 39.7 to 31.4 feet above sea level in August, 1979.

Average depths to water in the unconfined aquifer are shown in figure 3. These water levels were compiled in October 1959 (Boggess, Davis, and Coskery 1965), and seem to represent average water levels in the unconfined aquifer during 1951-61.

GROUND-WATER TEMPERATURE

Factors Affecting Ground-Water Temperature

Two primary sources add heat to ground water: geothermal heat, which moves upward from deep within the earth, and solar heat from the sun's radiation. This addition of heat is balanced by several mechanisms through which the temperature of ground water is decreased. The resultant ground-water temperature is determined by the thermal gains and losses affecting a specific drop of water at a specific time. These factors are shown in figure 4.

Heat is continually exchanged between land surface and the air, with heat moving from the warmer to the cooler body. During the day, the land surface is heated by radiation from the sun. Part of this heat is returned to the air by radiation and convection, and part is transmitted to underlying soil and water by conduction. Heat is also transmitted from land surface to the water table by precipitation moving downward through soil that has been heated by the sun. At night, heat is lost from land surface to the air by convection, and by radiation to the atmosphere. When the land surface becomes cooler than underlying soil layers, heat moves upward by conduction through soil grains and by convection in the pore spaces between the grains and is lost to the atmosphere.

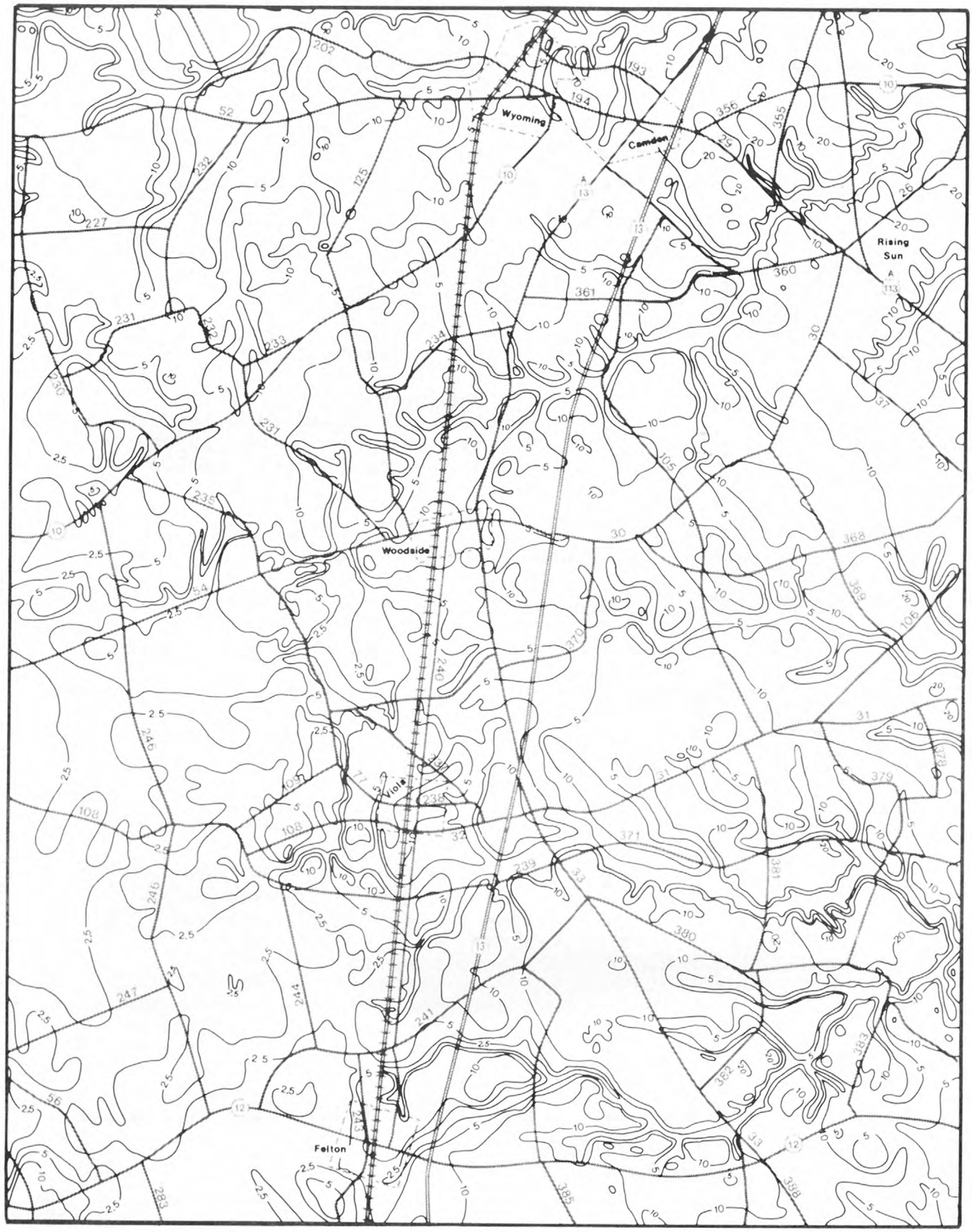


Figure 3. Water level, in feet, below land surface.

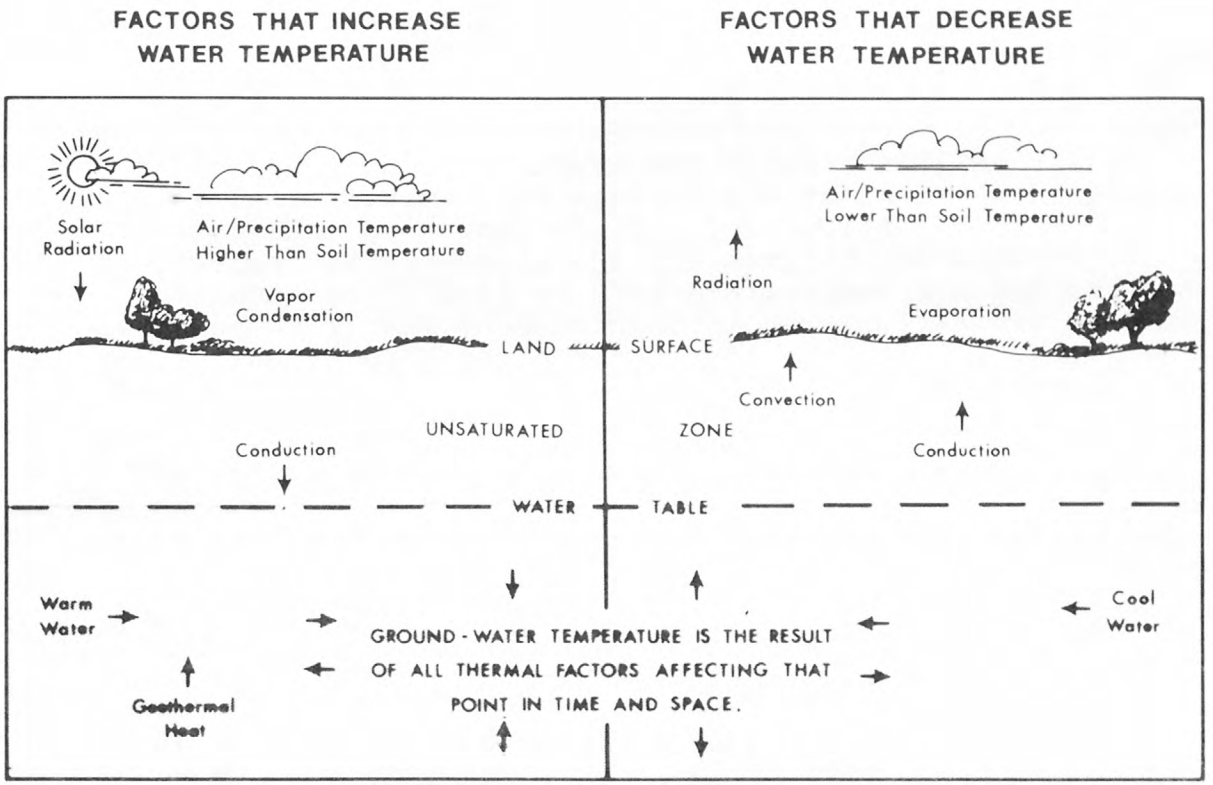


Figure 4. Factors affecting ground-water temperature.

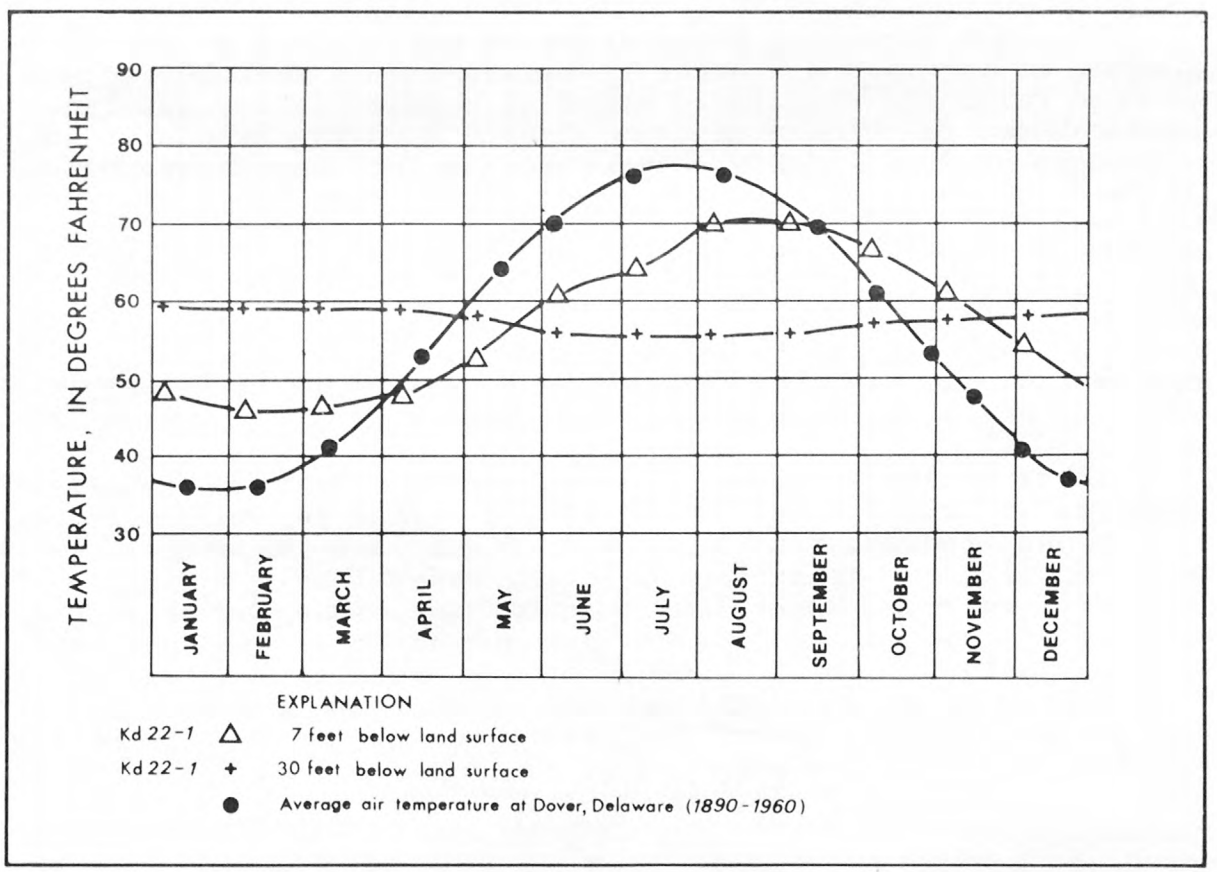


Figure 5. Monthly temperature of air and ground water.

Average ground-water temperature at land surface is approximately that of the average air temperature (fig. 5). As the distance below land surface increases, the effects of other factors become greater, and ground-water temperature lags behind air temperature both in time of maximum and minimum temperature and in magnitude of yearly temperature change. The influence of geothermal heat on ground-water temperature is most easily seen in the deep aquifers, and is discussed below.

Unconfined Aquifer

Water temperature in the upper part of the unconfined aquifer was measured twice each week in two wells instrumented with thermistors set at various depths. Water temperatures in 18 other wells were measured monthly by a thermistor probe lowered to the bottom of the well. Readings were taken at each foot below the water surface through this interval to give a temperature profile of the well.

Figure 6 shows the temperature in well Jc55-1 at the beginning of each month. Water temperature at 8 feet below land surface responded rapidly to seasonal changes in air and land temperature, reaching a minimum of 45.0°F during February and a maximum of 70.1°F during September. Water temperature below 30 feet however, responded to changing air and land temperature much more slowly, and had a much smaller range of fluctuation. At 35 feet, a minimum temperature of 56.0°F occurred during late August, and a maximum of 57.8°F was recorded during early February. Annual water-temperature distribution in this well is shown in figure 7. Lines of equal temperature in this figure have been smoothed to omit minor fluctuations caused by water-level changes and instrument resolution.

Figure 8 shows the minimum, average and maximum temperature measured in each project well during a 1-year period. Average values near the water table in this figure are subject to statistical error because of changing water levels during the period of record. Water levels in the unconfined aquifer usually are closest to land surface during the spring and at maximum depth below land surface during the fall. Abrupt changes in the slope of the maximum or minimum temperature curve may be caused by an increase or decrease in permeability of the aquifer at that elevation.

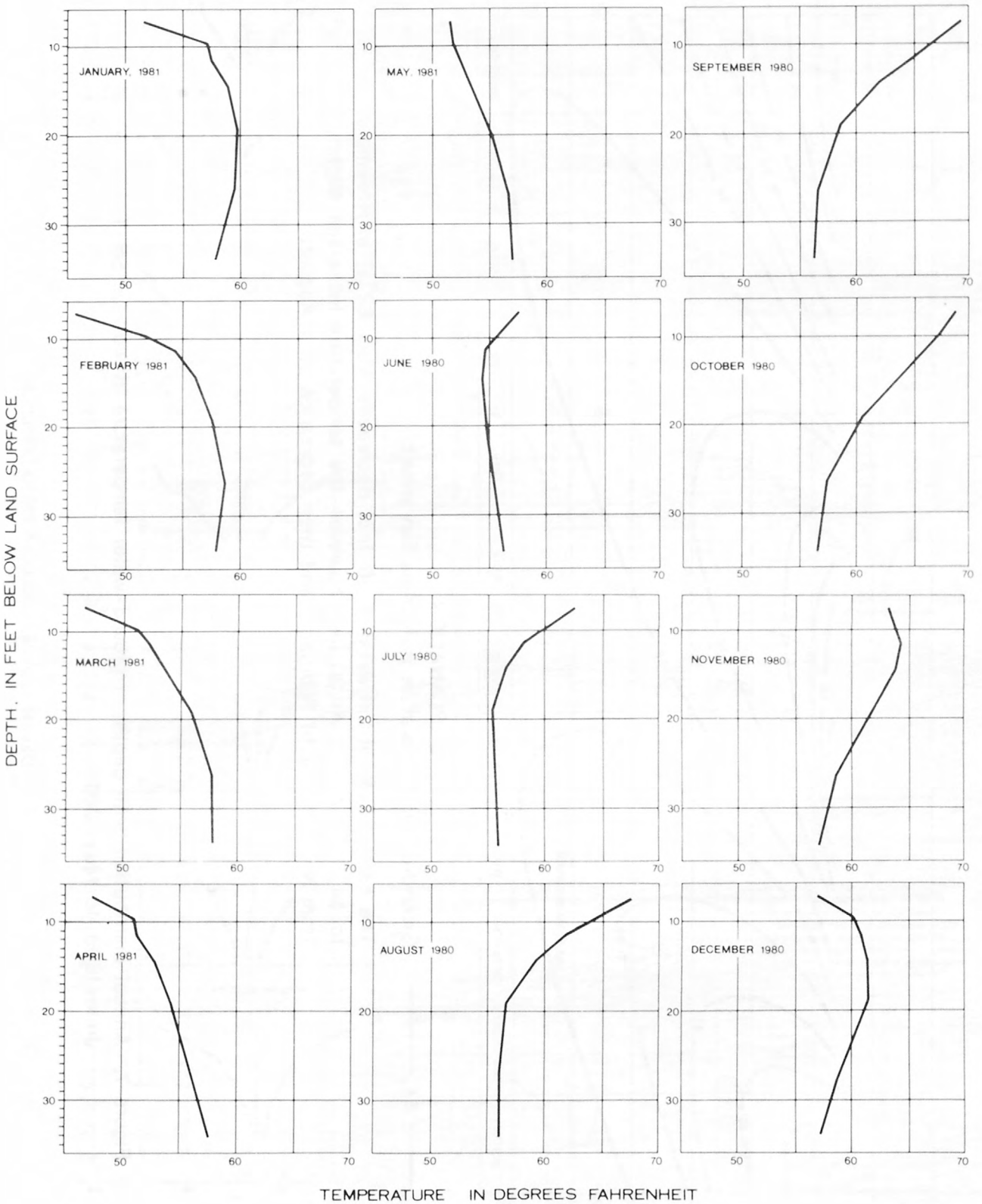
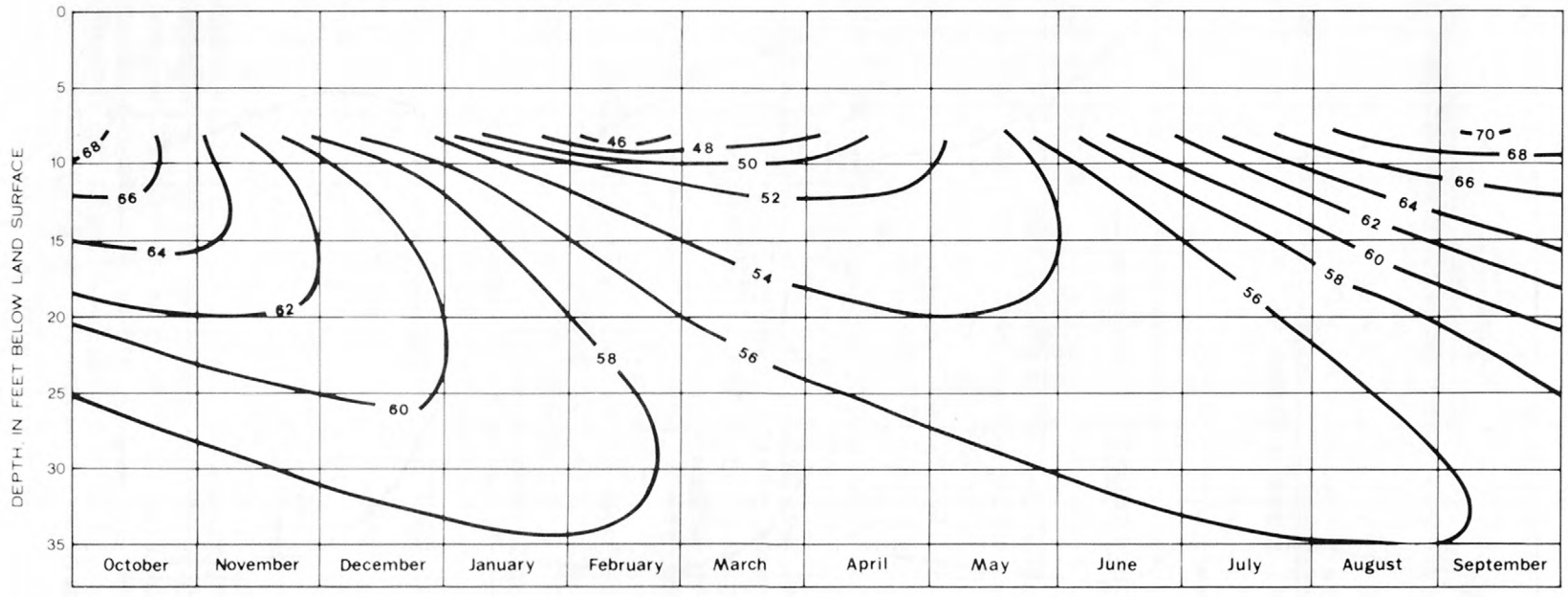


Figure 6. Temperature profiles, in well Jc 55-1



EXPLANATION

54 — Ground-water temperature in degrees Fahrenheit.

The temperature of the water at 20 feet decreases from 62° F. in November to 54° F. in April. At 30 feet, however, the temperature increases slightly from November until February, and then decreases until August.

Figure 7. Annual distribution, with depth, of ground-water temperature in well Jc 55-1, June 1980 to May 1981

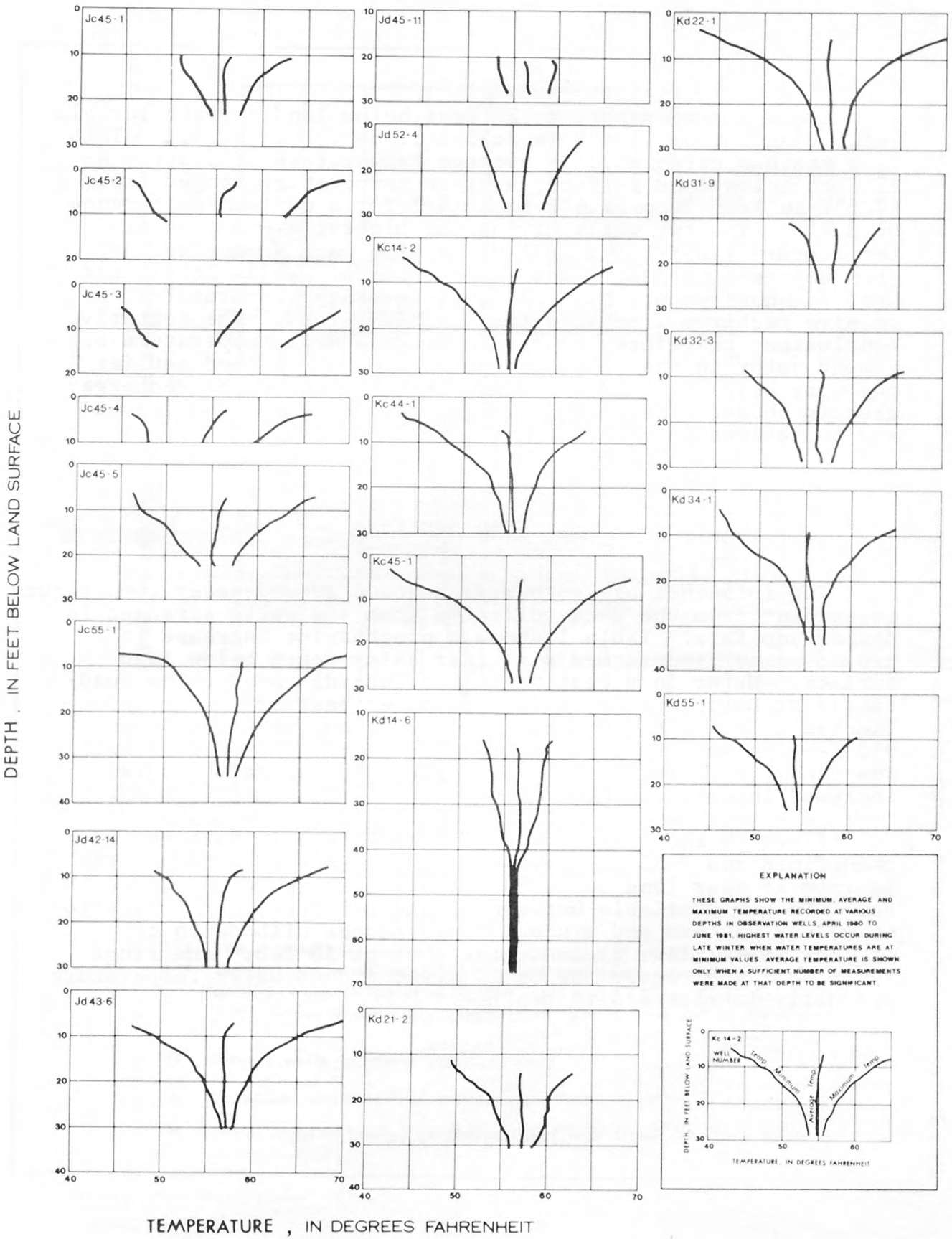


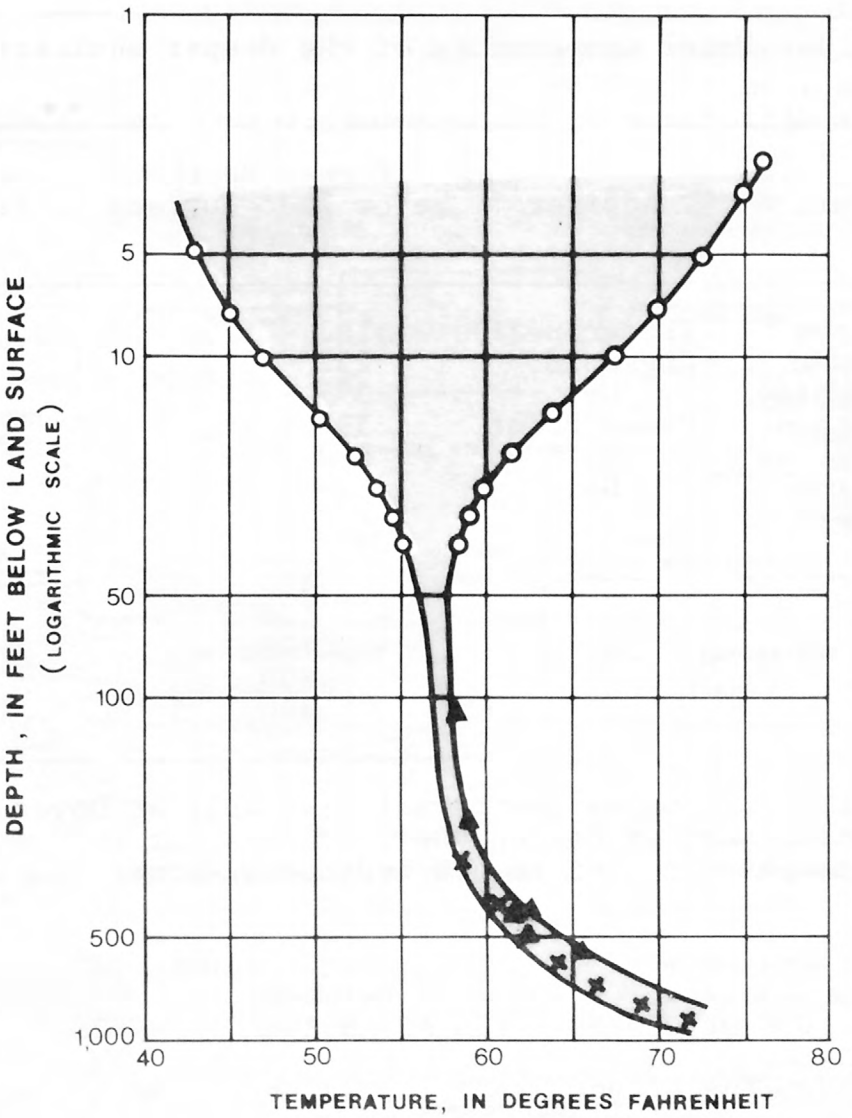
Figure 8. Minimum, average, maximum temperature of ground water in observation wells.

Average temperature at 20 feet below land surface for all wells ranges from 57.9°F in Jc55-1 to 54.6°F in Kd55-1. This is a maximum difference in average temperature of 3.3°F. At 25 feet below land surface, average temperature ranged from 57.8°F in Kd31-9 to 54.6°F in Kc14-2 for a maximum difference of 3.2°F. The two wells having the highest average water temperature (Jc55-1 and Kd31-9) receive warm summer recharge from adjacent unshaded black-topped roads. Wells Kc14-2 and Kd55-1, whose waters had the lowest average temperatures, receive recharge from forested or shaded land. The tentative conclusion, therefore, is that average annual temperature of ground water in the upper 25 feet of the unconfined aquifer may vary between 3 and 4°, depending on whether the recharge area is shaded. No correlation was found between soil type and variations in ground-water temperature.

Deep Aquifers

The influence of geothermal heat on ground-water temperature is evident from the data collected from six wells screened in deeper aquifers. Table 1 shows a progressive increase in ground-water temperature with increasing depth below land surface. Water in a test well just outside the Wyoming quadrangle at Dover Air Force Base, 4 miles east of Camden, increased in temperature 2.5°F per 100 feet between 300 and 955 feet below land surface. Water temperature in this well was estimated from Delaware Geological Survey data and is included in table 1.

Figure 9 shows the range of temperature in both the unconfined and deep aquifers of the Wyoming quadrangle. The maximum is near land surface and decreases rapidly with depth. Few data are available between 35 and 100 feet, but projection of yearly maximum and minimum temperatures with depth in project wells (fig. 8) indicates that at 50 feet, the range would be 2°F or less. Below 50 feet, ground-water temperature gradually increases with depth.



EXPLANATION

The shaded area shows the maximum range of ground-water temperature at different depths. At 5 feet below land surface, ground-water temperature ranges from about 43° to 72° F. At 500 feet, however water temperature ranges from 61° to 65° F.

o Project wells, monthly measurements

▲ Municipal and industrial wells,(single measurements)

× Department of Energy geothermal test well, Dover Air Force Base

Figure 9. Range of ground-water temperature at different depths.

Table 1.--Water temperature of the deeper aquifers.

Well no.	Location	Aquifer	Screen depth below land surface (feet)	Temperature (°Fahrenheit)
Kd51-1	Felton	Frederica(?)	100 - 170	58.4
Jd44-28	Camden	Cheswold	232 - 243	58.7
Kd13-1	Woodside	Do	397 - 420	62.4
Jd45-6	Lebanon	Piney Point	397 - 447	61.6
Kd11-8	Woodside	Do	430 - 490	62.4
Kd51-5	Felton	Do	510 - 580	65.5
Je43-2	Dover*		300	58.5
			400	60.9
			500	62.4
			600	64.1
			700	66.4
			800	69.0
			900	71.9

* U.S. Department of Energy geothermal test well at Dover Air Force Base, 4 miles east of Camden, Del. Values for this well are from the temperature log at the indicated depths.

USE OF GROUND WATER AS AN ENERGY SOURCE

The Ground-Water-Source Heat Pump

The principle of operation of the ground-water-source heat pump (fig. 10) is the same as that of a refrigerator, which moves heat from one place to another by means of a low boiling-point fluid. This fluid in the heat pump absorbs heat from ground water in a heat exchanger, converting the fluid to a gas. A compressor then increases the temperature and pressure of the gas, and moves it to a second heat exchanger, where the gas transfers heat to the air and condenses to a liquid. A fan moves air across this second heat exchanger and circulates the warm air through the space-heating system. The fluid then passes through a small diameter (capillary) tube, which decreases the pressure of the liquid before it returns to the ground-water heat exchanger. If the direction of flow through the system is reversed, heat is removed from the conditioned space and added to the ground water, thus forming an air-conditioning system.

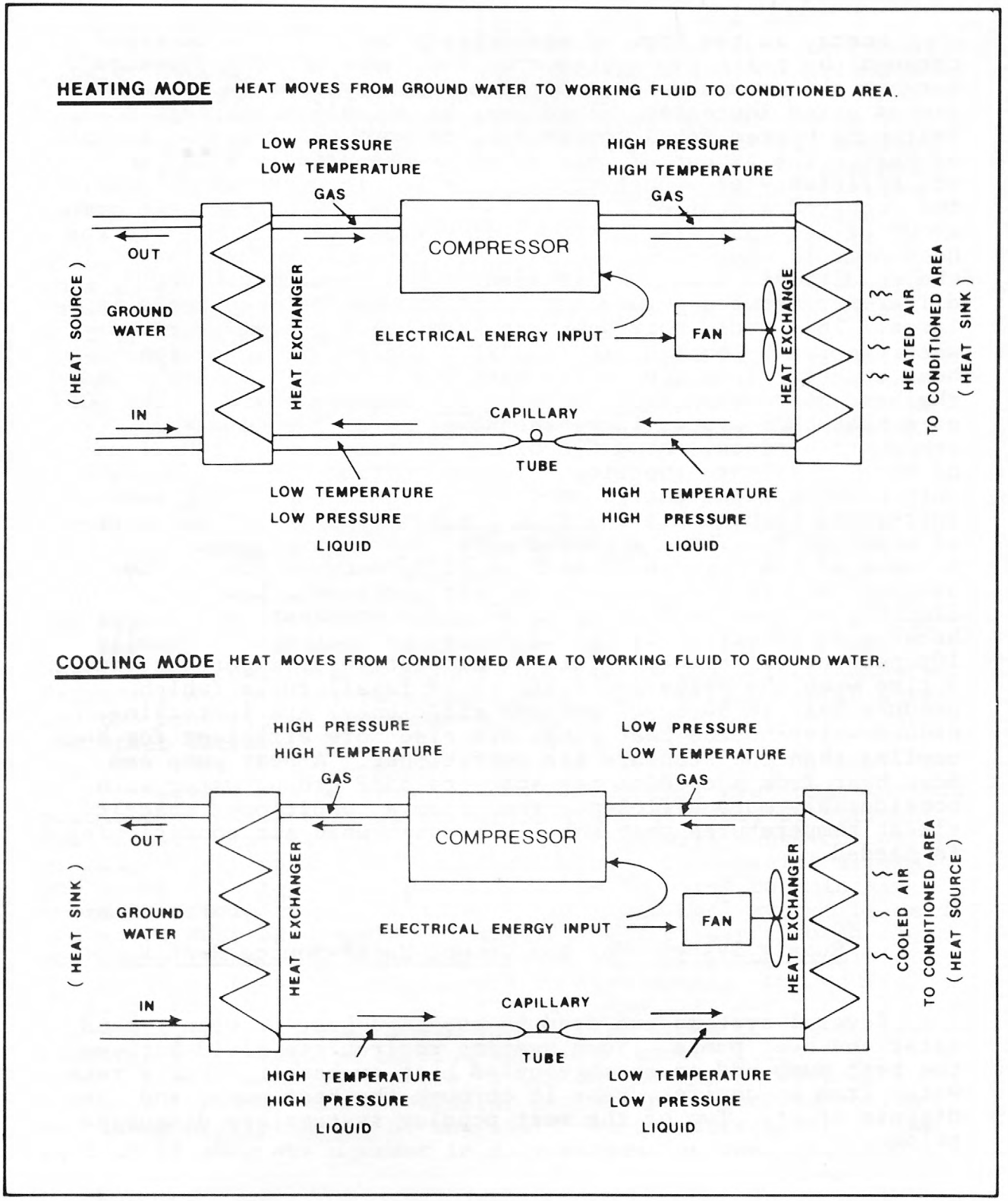


Figure 10. Principle of operation of the ground-water-source heat pump.

Energy in the form of electricity is used to move fluid through the heat-pump system. As the temperature difference between the ground water and the air temperature in the conditioned space increases, fluid must be circulated through the heat-pump system for a longer time to move the required amount of heat. The amount of heat moved is measured in BTUs, and the efficiency of a heat pump in the heating mode to deliver the required amount of BTUs is called the COP of the heat pump. A COP of 1:1 indicates that the electrical energy input to the heat pump is equal to the amount of heat energy supplied to the conditioned space. This occurs when the temperature difference between ground water and the conditioned space is large. This would correspond to home heating from a ground-water source below freezing (32°F). Under this condition, heat transfer from ice to the heat pump fluid is minimal, and the heat pump essentially acts as an electric heater. The COP of a heat-pump system increases however, as ground-water temperature rises. At a COP of 3.5:1, three and one-half units of heat energy are supplied to the conditioned space for each unit of electrical energy used by the heat pump. This would correspond to home heating from ground water at a temperature of about 65°F. Thus, a ground-water-source heat pump is capable of heating a home with an efficiency of 100 to 350 percent or more compared to electric resistance heating. Electric resistance heating is used for comparative purposes because it converts electrical energy to heat with virtually 100 percent efficiency. This is of particular importance at a time when the price and scarcity of fossil fuels (which produce heat at 50 to 80 percent efficiency) are increasing. Ground-water-source heat pumps are also more efficient for home cooling than the standard air conditioner. A heat pump can move heat from a conditioned space to 55°F ground water with considerably more efficiency than from a conditioned space to air at temperatures that usually prevail when air conditioning is needed.

Supply Systems for the Ground-Water-Source Heat Pump

Several systems are used to exchange heat between ground water and heat pumps. Some systems recirculate fluid between the heat pump and an earth-coupled heat exchanger; others take water from an aquifer, pass it through the heat pump, and then dispose of it. Two of the most popular systems are discussed below.

The buried loop system consists of a continuous length of pipe or tubing buried as deeply as practical below land surface. It contains a mixture of water, corrosion inhibitors, and anti-freeze that either takes heat from or rejects heat to the soil or ground water as it is circulated through the loop. Because it is a closed system, a constant water quality is maintained within the loop. Problems with corrosion and scale formation in the heat exchanger are thereby avoided. The major disadvantage of this system is that the practical depth limit to which pipe can be buried is 4 to 5 feet below land surface. This is generally within the range of fluctuation of the water table. When ground-water levels drop below the buried pipe, heat is exchanged between the pipe and dry soil at a much slower rate than between the pipe and saturated aquifer material. Additionally, water temperature within 5 feet of land surface is warmest in the summer and coolest in the winter. Thus, the heat pump has a lower COP in the heating mode, and a lower EER in the cooling mode.

Ground-water temperature at 30 feet below land surface in the Wyoming, Delaware quadrangle varies about 3° seasonally. At 30 feet below land surface, highest temperatures coincide with the heating season, and lowest temperatures with the air-conditioning season. If water from this depth is supplied to the heat pump, maximum efficiency is realized in both the heating and cooling modes. The quantity of water required for heating and cooling a home is as much as 15 gallons per minute, depending on the difference in temperature between ground water and the conditioned space, insulation of the conditioned space, and other factors.

Disadvantages of ground water to supply a heat pump include possible problems with water quality, and disposal of effluent. Ground water may contain constituents that will cause corrosion or scale build-up in some heat exchangers, and special alloys and provisions for scale removal may be required to maintain thermal efficiency of the system. If a one-well system is used, the water must be disposed of after it has passed through the heat pump. State agencies regulating water use may prohibit discharge of this water to sewers or open drains and require an additional well (recharge well) at some distance from the withdrawal well through which water is returned to the aquifer. Recharge wells require careful design to avoid decreasing capacity and eventual failure, which may result in several ways. Changing the temperature of water containing dissolved solids may cause precipitation of the solids on the screen, or in the aquifer if they are present in near-saturation concentrations.

Withdrawing water from one aquifer and recharging it into a different aquifer containing water of different chemical quality may cause chemical precipitation in the host aquifer. Introduction of oxygen into water during recharge can cause precipitation of several chemical constituents normally found in water and contribute to organic growth in the well and aquifer. Because of these factors, water should be recharged into the same aquifer at the same elevation from which it was withdrawn. Recharge water should be piped to an elevation below the water table in the recharge well to prevent oxygenation, and the well should be chlorinated and fitted with a sanitary seal to prevent organic growth.

The Annual Thermal Storage System

The idea of saving summer's excessive heat to provide warmth during the winter has always been tantalizing. Under the right hydrologic conditions, the ground-water-source heat pump can do just that -- recover heat that was rejected to ground water during cooling-mode operation to increase the efficiency of the heat pump in the heating mode. Conversely, during the heating season, ground water is cooled as heat is extracted from it. If this cooled water can be supplied to the heat pump during the summer, it will increase the efficiency of the system operating in the cooling mode.

Figure 11 gives the altitude of the water table, in feet above sea level, in October, 1959 (Boggess and others, 1965). Ground water moves from higher to lower altitude, and perpendicular to the contours shown. The distance between the contours on figure 11 can be used to estimate hydraulic gradient:

$$\frac{(5{,}280 \text{ ft/mile}) \quad (\text{difference in altitude between contours, ft})}{(\text{distance between contours, ft})} = \text{hydraulic gradient, ft/mile}$$

Hydraulic gradients in the unconfined aquifer range from near 1 ft/mile in the southwestern part of the quadrangle to 176 ft/mile in the southeastern part.

Figure 11. Altitude of the water table, October 1959

The average velocity of water movement through the unconfined aquifer is dependent on several factors, including horizontal hydraulic conductivity and porosity of the aquifer and hydraulic gradient of the water table. As the percentage of fine-grained material in an aquifer increases, the velocity of water moving through it will decrease if hydraulic gradient and aquifer porosity remain constant.

Johnston (1973, 1977) showed a hydraulic conductivity of the unconfined aquifer in the Wyoming Quadrangle of about 80 ft/day, and a storage coefficient (approximately equal to effective porosity) of 0.14. Applying these values to the equation for average velocity of ground-water movement:

$$\text{Average velocity (ft/day)} = \frac{\text{Hydraulic conductivity (ft/day)} \times \text{Hydraulic gradient (ft/ft)}}{\text{Effective porosity}}$$

(Lohman, 1979, p. 10) gives the following results:

Hydraulic gradient in ft/mile determined from fig. 11	Average ground-water velocity	
	Feet per day	Feet per 6 months
1	0.108	19.76
10	1.08	197.6
100	10.8	1981.
176	19.0	3467.

Thus, the average distance that water moves during 6 months in the unconfined aquifer may range from about 20 to 3,000 feet. Actual velocity of flow through an aquifer at a specific location will be affected by aquifer composition and proximity of nearby recharge and withdrawal wells. This can be determined by a detailed analysis of geologic and hydrologic factors.

Assume that a ground-water-source heat pump system is to be installed in a low-to-moderate gradient area. If the recharge well is installed upgradient and at a properly selected distance from the withdrawal well, the annual heating and cooling efficiency of the system can be significantly increased by recycling rejected heated or cooled water. This will occur if the recharge and withdrawal wells are spaced so that travel time of ground water between the wells is 5 to 6 months. This system cannot be used effectively in areas having high velocities of ground-water movement because of the large distances needed between withdrawal and recharge wells, and transient dilution of the heated or cooled water.

The rate of water movement in artesian aquifers (several feet to several tens of feet per year) is generally much slower than that in unconfined aquifers. Under these conditions, withdrawal and recharge wells can be alternated seasonally to increase system efficiency. If two wells, A and B are used, water withdrawn from well A during the heating season is cooled as heat is extracted from it and returned to well B. During the summer, the direction of flow is reversed, and the cooled water from well B increases the EER of the heat pump in the air-conditioning mode. Heat rejected from the conditioned space is added to the water and returned to the aquifer through well A. Thus, summer heat and winter cold are stored in the aquifer for later use. Again, geologic conditions, pumping rates, and local hydraulic gradients will have considerable effect on the design of such a system. Proper spacing of wells can only be determined on the basis of local conditions.

GROUND-WATER QUALITY

Table 2 shows the chemical constituents in water from three wells in the unconfined aquifer and three in the Piney Point aquifer. Water from the unconfined aquifer is somewhat acidic, with low alkalinity, and moderately low dissolved solids. Water from the Piney Point aquifer, however, contains about three times as much dissolved solids as the water from the unconfined aquifer. The primary constituents of water in the Piney Point aquifer are sodium and bicarbonate.

Ideally, water for heat pumps should be neither acidic nor basic (pH = 7.0) and contain no dissolved gases, to prevent corrosion of the heat exchanger. In addition, the water should contain no iron, manganese, silica, or carbonate, which cause scale and encrustation. Because water from the unconfined aquifer has a low pH and contains some iron and dissolved solids, and water from the Piney Point aquifer is high in dissolved solids and bicarbonate, the material constituting the heat-pump heat exchanger needs to be selected for compatibility with the source water.

TABLE 2 .-- CHEMICAL ANALYSES OF GROUND WATER FROM WELLS IN THE WYOMING QUADRANGLE

Parameter	Units	Jd42-14	Jd45-6	Kc44-1	Kd11-8	Kd32-3	Kd51-5
Sample date	-	06/16/81	02/09/76	06/16/81	06/22/70	06/16/81	03/30/70
Geologic Unit Name-Aquifer	-	Unconfined	Piney Point	Unconfined	Piney Point	Unconfined	Piney Point
Depth, bottom sample interval	Ft	39	447	30	448	26	551
Elevation of land surface	Ft	45	32	60	60	42	50
Temperature, Water	°C	15.0		14.5	18.0	16.5	17.0
Color	Pt-Co Units		0		2		3
Specific conductance	Micromhos	175	506	63	502	158	566
pH Field	Units	4.5	8.0	5.3	8.1	5.0	8.2
pH Laboratory	Units	5.3		6.1		5.9	
Solids, dissolved	MG/L	114	308	46		100	
Solids, residue at 180°C	MG/L	120	304	63	331	119	351
Sodium Adsorption Ratio	-	0.3	3.9	1.2		0.4	
Carbon dioxide, CO_2	MG/L		3.9				
Nitrogen, $NO_2 + NO_3$	MG/L	5.7	0.10	0.03	.90	5.5	.90
Oxygen, dissolved	MG/L	3.2		1.8		5.5	
Hardness, as $CaCO_3$	MG/L	60	85	7		52	
Hardness, noncarbonate	MG/L	53	0	0		50	
Carbonate as CO_3	MG/L		0		--		0
Bicarbonate as HCO_3	MG/L		322		349		347
Alkalinity as $CaCO_3$	MG/L	7	264	13		2	
Chloride	MG/L	11	4.6	2.7	3.4	11	7.2
Fluoride	MG/L	< 0.1	0.8	< 0.1	.8	< 0.1	1.6
Silica	MG/L	19	22	20	23	20	9.8
Sulfate	MG/L	29	3.3	4.5	4.4	17	11
Calcium	MG/L	9.2	18	1.9	14	14	7.4
Iron, dissolved	UG/L	60	0	90		90	
Iron, total recoverable	UG/L				10		80
Magnesium	MG/L	9.1	9.8	0.6	8.1	4.1	5.3
Manganese, dissolved	UG/L	60	0	8		8	
Manganese, total recoverable	UG/L				< 5		< 5
Potassium, dissolved	MG/L	1.5	9.2	0.8	8.6	1.5	8.0
Sodium, dissolved	MG/L	5.9	82	7.1	105	7.2	121

REGIONAL APPLICATION OF THESE DATA

Much of the information in this report is applicable to other areas underlain by unconsolidated sediments. Groundwater temperature will vary, depending on average annual air temperature, solar insolation and other climatologic factors; but these data in this report should be reasonably transferable throughout the Delmarva Peninsula south of New Castle County, Delaware.

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GLOSSARY

The definitions and explanations given below are for the use intended in this report only. Many terms have wider definitions than those given.

Alkalinity - The capacity of a solution to neutralize acid.

Aquifer - A deposit of sand or gravel that contains saturated permeable material capable of yielding significant quantities of water to wells and springs.

Artesian aquifer or confined aquifer - An aquifer containing water confined under pressure between relatively impermeable or significantly less permeable material. Water in a well screened in an artesian aquifer will rise above the top of the aquifer.

BTU (British thermal unit) - The quantity of heat required to raise 1 pound of water 1 degree Fahrenheit.

Conditioned space - An enclosed space that is either heated or cooled.

Conduction - Transfer of heat through a solid or liquid medium without movement of the transmitting medium.

Convection - Transfer of heat by air or water as a result of movement of air or water.

COP (coefficient of performance) - A measure of the amount of heat energy produced by a heat pump relative to the amount of electrical energy used by the heat pump to produce that heat. [A COP of 1.0 indicates that the heat energy output is equivalent to the electrical energy input. A COP of 3.0 indicates that three times as much heat energy is being produced than the amount that would result from conversion of input electrical energy alone to heat.]

Deep aquifers - Those aquifers below the unconfined aquifer in the Wyoming quadrangle.

Dissolved solids - Chemical constituents in solution in water.

Earth-coupled heat exchanger - A closed system that contains a low-freezing-point fluid that circulates through either a horizontal loop of pipe buried below land surface or through one or more sealed vertical casings that may or may not extend below the water table.

EER (energy efficiency ratio) - A measure of the amount of cooling produced by a heat pump relative to the amount of electrical energy used to produce that cooling.

Geothermal heat - Heat generated deep within the earth by the decay of radioactive elements.

Ground water - Water in openings between soil and rock particles.

Ground-water divide - A line marking the local maximum altitude of the water table. [Ground water moves in opposite directions away from this line.]

Heat exchanger - An arrangement of concentric or adjacent pipes that allows the heat in one fluid to be transferred to another fluid without mixing of the fluids.

Heat pump - An electro-mechanical device that can either heat or cool a conditioned space by transferring heat from one fluid (including air) to another.

Hydraulic conductivity - A property of an aquifer material that determines the rate of water movement through that material. Equivalent to permeability in this report.

Hydraulic gradient - The change in water level per unit of distance in the direction of maximum change.

Instrument resolution - The smallest difference (in temperature) that an instrument will show. [The instruments used in this study have a resolution of 0.1°F].

One-well system - A supply system for a heat pump that withdraws water from a well and discharges the used water; usually to a sewer, pond, or stream.

Permeability - A property of a porous medium that is a measure of the relative ease with which the medium can transmit a fluid between two points having different pressures.

pH (hydrogen-ion activity) - A measure of the acidity or alkalinity of a solution. [The usual range of ground water is from pH 5.0, which is acidic, through pH 7.0, which is neutral, to pH 8.5, which is alkaline.]

Porosity - The amount of open space between soil or rock particles expressed as a decimal fraction or percentage of the total volume of a sample. [Effective porosity is the amount of interconnected open space available for fluid transmission.]

Quadrangle - A map covering 7-1/2 degrees of latitude and 7-1/2 degrees of longitude [approximately a rectangle.]

Radiation - Propagation of energy by electromagnetic waves.

Recharge - Water, generally from precipitation or streams, that replenishes an aquifer.

Recharge well - A well through which water is pumped or allowed to flow by gravity into an aquifer.

Scale formation - The buildup of oxides and precipitated dissolved solids on heat-exchange surfaces.

Storage coefficient - The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in water level.

Thermistor - A transistorlike device having electrical resistance that changes in response to varying temperature.

Two-well system - A heat-pump system having one well used as a source of water and one well used to dispose of water.

Unconfined aquifer - An aquifer in which the surface of the water (water table) is at atmospheric pressure.

Unconsolidated sediments - Gravel, sand, silt and clay that has not hardened into rock.

Water table - The surface of the saturated part of an unconfined aquifer.

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