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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

EVALUATION OF SHALLOW AQUIFERS IN THE HELENA VALLEY, LEWIS AND CLARK COUNTY, MONTANA

By Joe A. Moreland and Robert B. Leonard

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METRIC CONVERSION TABLE

The following factors can be used to convert inch-pound units in this report to the International System (SI) of metric units.

Mutiply inch-pound unit	By	To obtain metric unit
acre	4047	square meter
cubic foot per day (ft^3/d)	0.02832	cubic meter per day
foot	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon	3.785	liter
gallon per day (gal/d)	3.785	liter per day
gallon per minute (gal/min)	0.06309	liter per second
inch	0.02540	meter
mho	1.0	siemens
mile	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

temperature, degrees Celsius ($^{\circ}$C) = 0.556 ($^{\circ}$F-32)

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ABSTRACT

Shallow aquifers underlying the Helena Valley in west-central Montana were evaluated in response to a general concern about the potential for contamination from sewage effluent and other wastes. Water-level data collected from 52 test wells augered in the valley were used to construct a depth-to-water map that shows large areas underlain by shallow ground water (less than 5 feet below land surface). Hydrographs for selected wells show that water-level fluctuations range from about 15 feet near the margins of the valley to about 2 feet in lower lying areas. Although water levels in wells in most areas of the valley are highest during July or August, some water levels are highest during the spring months.

Aquifer tests in five wells indicate that transmissivity of the unconsolidated sand and gravel aquifers is about 1×10^4 feet squared per day. The tests also indicate that pumping can induce or increase the rate of drainage from the saturated material overlying the shallow aquifers.

Water samples collected from the test wells and from 11 domestic wells show that water quality is generally acceptable for domestic use, although nitrate concentrations exceeded 10 milligrams per liter in two of the test wells. On-site determinations of nitrate concentration and specific conductance of samples from the test wells and from 98 domestic wells show significant variations. The largest nitrate concentration for water from a domestic well was 7.6 milligrams per liter. The largest specific conductance determined was 1,620 micromhos per centimeter at 25° Celsius in a test well. Large values for both nitrate and specific conductance are related to the impacts of man's activities in many parts of the valley.

INTRODUCTION

The Helena Valley is a rapidly developing area of about 100 mi^2 north and east of Helena, Mont. (fig. 1). Most of the nearly 5,000 valley residents obtain water for domestic use from individual wells. A few subdivisions are served by community wells and central distribution systems. Most of the residents depend on septic tanks and soil-absorption systems (drain fields) for sewage disposal. A few subdivisions have central collection systems for disposal of domestic wastes in sewage lagoons. The shift from rural to suburban land use has been accompanied by increased withdrawal of ground water and discharge of effluent waste by domestic water systems, normally in close proximity.

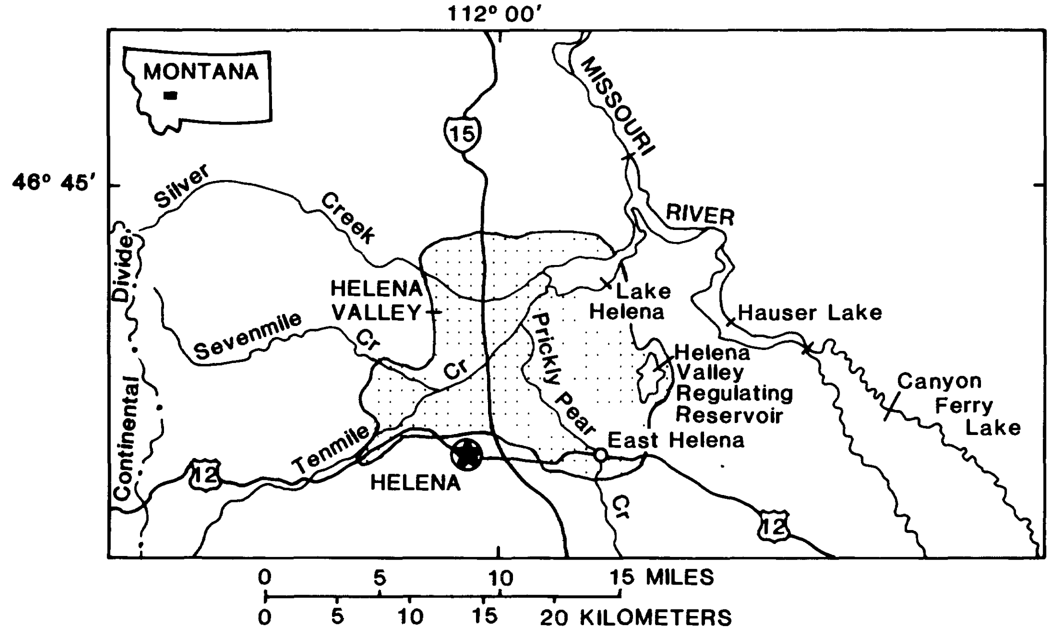


Figure 1.--Location of Helena Valley.

Sewage effluent may contain many chemical and biological contaminants that, if disposed in the ground water, could render it unfit for human consumption. Chemical pollutants are as numerous as the household products which find their way to the kitchen sink. Detergents, solvents, pesticides, drain cleaners, petroleum products, food preservatives, and even unused medicine are commonly disposed down household drains. Some, such as nonbiodegradable detergents, can cause nuisance problems (in this instance, foaming), whereas others are toxic even in minute concentrations. Biological contaminants such as bacteria and virus could result in widespread outbreaks of contagious diseases including influenza, hepatitis, and cholera.

Residents of the valley and county officials are concerned that sewage effluent from soil-absorption systems and lagoons, as well as industrial (smelter), municipal, and agricultural waste, may percolate to the shallow aquifers. Although most domestic wells in the valley are drilled through at least one layer of fine-grained material to avoid the potentially contaminated water in the shallowest aquifers, sewage effluent eventually may percolate downward to the aquifers used for domestic supply. Chemical or biological contamination of the ground water could deprive the residents of an economical potable water supply. The rapid increase in population density might accelerate the rate and severity, as well as the economic effects, of contamination. In response to the general concern, the Lewis and Clark County Commissioners requested an investigation of the potential for contamination of the shallow aquifers in the area. This report summarizes the findings of that investigation.

Purpose and scope

The purpose of the study was: (1) To evaluate the geologic and hydrologic factors that control the movement of water and potential contaminants into and within the shallow aquifers, and (2) to describe current ground-water quality and historic changes. The following specific objectives are useful for evaluating the potential for degradation of domestic water supplies, caused by downward movement of effluent waste:

1. Determine the depth to ground water and the magnitude of seasonal variations in the water table.
   (Physical, biological, and chemical changes occur in the soil zones above the water table. Oxygen in the unsaturated zone initiates chemical changes (oxidation) and sustains biological activity (decomposition) that can alter or neutralize many of the potential contaminants.)

2. Determine the lateral and vertical extent of layered fine-grained sediment that might prevent or retard downward percolation of contaminated shallow water into the aquifers used for water supply.
   (Valley residents have placed much faith in stratification of ground water. The alluvial sediments that comprise the aquifers underlying the valley consist of alternating layers of gravel, sand, silt, and clay. This layering causes ground water to move preferentially in a horizontal direction through the coarse-grained material rather than vertically across the less permeable fine-grained layers. Thus, water entering the ground-water system at the top of the saturated zone (as sewage effluent) would tend to remain there unless vertical hydraulic-head differences existed to drive water downward. In areas where layers of silty clay or clay exist near the surface, the contaminants might be effectively perched above the underlying ground water. Even in areas underlain by fine-grained material, improperly constructed wells could provide an avenue for downward moving water between the casing and the well bore. Also, if fine-grained layers are absent or discontinuous, contaminants could move vertically under certain hydrologic conditions.)

3. Determine the transmissivity of the aquifers for estimating the rate of movement of water through the aquifer.
   (If the total pollutant load is small compared to the amount of water moving through the aquifers, simple dilution may afford protection. Therefore, a knowledge of the total underflow would be useful in assessing the potential for contamination. The transmissivity can be used with water-level gradients to determine the rate of ground-water flow.)

As part of the study, the U.S. Geological Survey augered 52 test holes at selected locations (see pl. 1) throughout the valley. The holes ranged in depth from 19.6 to 67.0 feet and were cased with unperforated steel pipe. Perforated sand points 30 inches long were installed at the bottom of each test hole. Water-level measurements and water samples were obtained periodically from these test wells from the fall of 1978 to the fall of 1979. A total of 165 samples from the test wells were analyzed for chemical constituents.

In addition, water samples were collected from 98 domestic wells in May and June 1979 to document current water-quality conditions in the aquifers being used for domestic supplies. Measurements of water temperature, specific conductance, and nitrate concentration were made at the well sites. To further document water quality, samples from 11 wells were analyzed for the most common major and minor constituents.

Gamma-ray geophysical logs were obtained from selected wells to determine the location of fine-grained sediments. Used in conjunction with drillers' logs, the geophysical logs provided an indication of vertical and areal extent of silt and clay deposits that could prevent or retard downward percolation of effluent.

The transmissivity and other properties of the aquifers were determined from aquifer tests conducted at five well sites. This information, together with water-level gradients, is useful in estimating the amount and direction of ground water moving through the system.

The water-quality analyses and water-level data are contained in a report by Moreland, Leonard, Reed, Clausen, and Wood (1979). Gamma-ray logs are on file in the U.S. Geological Survey office in Helena, Mont.

Numbering system for wells

In this report, sites are numbered according to geographic position within the rectangular grid system used by the U.S. Bureau of Land Management (fig. 2). The location number consists of as many as 14 characters. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position west (W) of the Montana Principal Meridian. The next two characters are the section number. The next three or four characters designate the quarter section (160-acre tract), quarter-quarter section (40-acre tract), quarter-quarter-quarter section (10-acre tract), and quarter-quarter-quarter-quarter section (2 1/2-acre tract) in which the well is located. The subdivisions of the section are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. The final two characters are sequence numbers that represent the order in which the wells are inventoried. For example, as shown on figure 2, well 11N03W21BAAA01 is the first well inventoried in the NE1/4 NE1/4 NE1/4 NW1/4 sec. 21, T. 11 N., R. 3 W.

Acknowledgments

This cooperative study was funded by the U.S. Geological Survey, the Lewis and Clark County Commissioners, and the Montana Bureau of Mines and Geology. Personnel of the City-County Health Department assisted in gaining access to drill the test holes, in collecting data, and in analyzing the information.

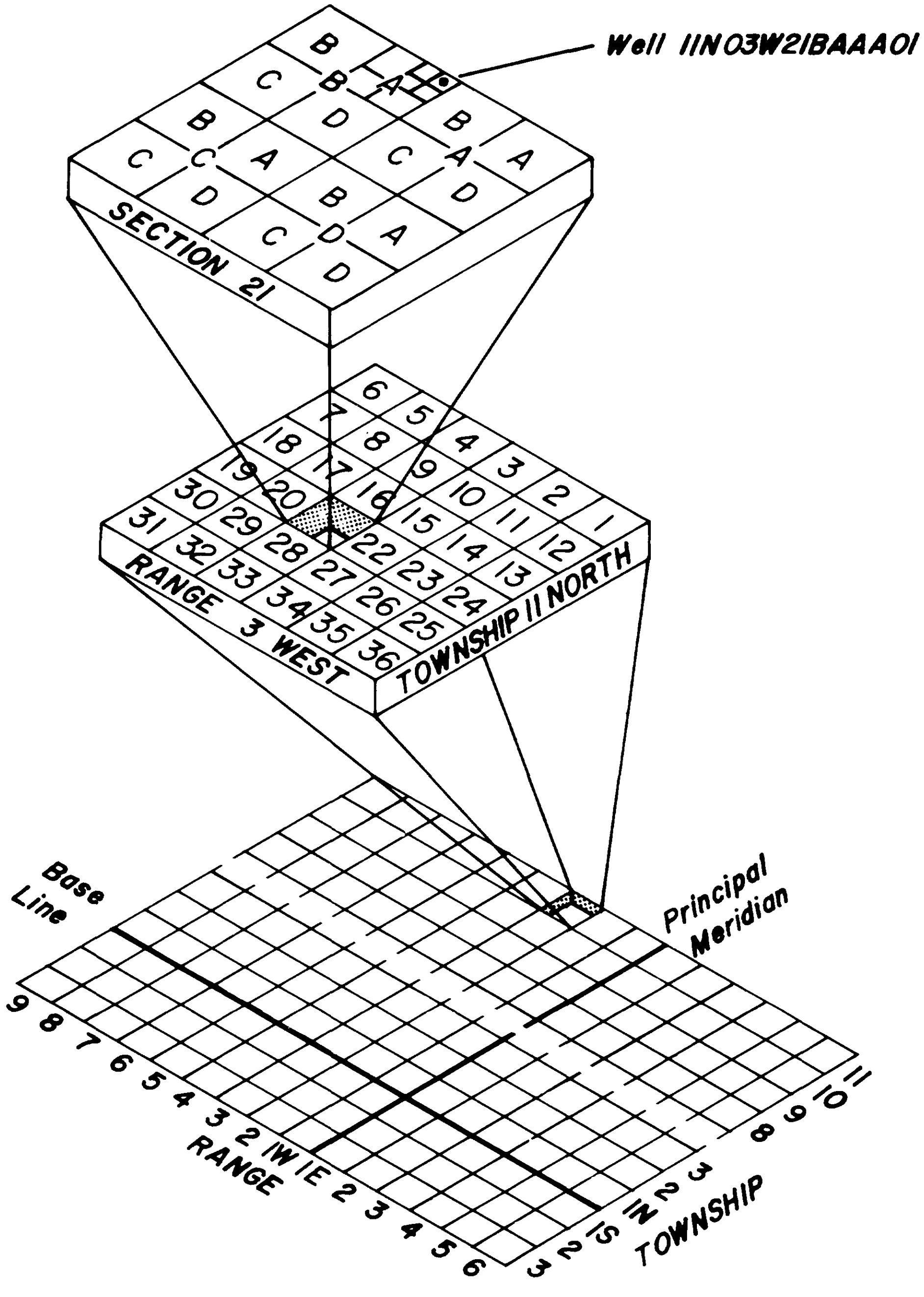


Figure 2.--System for numbering wells.

Many of the water samples analyzed as part of this investigation were collected by Charlotte Beckett, City-County Health Department. Her efforts contributed greatly to the successful completion of the study. Most of the chemical analyses reported in this study were made by the Montana Bureau of Mines and Geology, Analytical Division. Local landowners who granted access to their property for installing test wells, monitoring water levels, collecting water samples, and conducting aquifer tests also contributed significantly to the study.

GEOHYDROLOGY

Geohydrologic setting

The Helena Valley is a basin filled with a thick accumulation of unconsolidated material. Folded and faulted sedimentary, metamorphic, and igneous rocks underlie the unconsolidated material and form the hills and mountains surrounding the valley. Detailed descriptions of the geology can be found in reports by Knopf (1913), Lorenz and Swenson (1951), Knopf (1963), and Schmidt (1977).

The unconsolidated material has been divided into three categories (Lorenz and Swenson, 1951): (1) Deposits of Tertiary age composed predominantly of clays of volcanic origin--interbedded with these clays, or "lake beds" as they are commonly called, are thin layers of sand, gravel, and lignite; (2) gravels of Pliocene age deposited locally atop the "lake beds"; and (3) deposits of Quaternary age that mantle the valley floor and consist of clay, silt, sand, gravel, and cobbles carried into the valley mainly by streams and deposited as alluvial fans.

The precise thickness and extent of the Tertiary and Quaternary deposits are unknown. Knopf (1913) reported that wells were drilled to depths of as much as 1,200 feet without reaching the base of Tertiary deposits. Relatively little information is available on the character of the material below depths of about 200 feet.

The older, fine-grained "lake beds," which underlie the alluvial material and crop out in the eastern and southern parts of the valley, yield only small quantities of water to wells. In some areas, particularly along the northern margins of the valley where alluvial deposits are thin, wells completed in the "lake beds" yield less than 10 gal/min.

The sand and gravel layers of Quaternary age yield water freely to wells. Sufficient layers of sand and gravel can be found at virtually every location in the valley to provide an adequate supply of water to wells for domestic purposes. Because of the heterogeneous nature of the sediments, the layers of sand and gravel form a complex, but generally interconnected, system of aquifer zones that are considered as one multiple-aquifer system. Several large-capacity wells (pumping in excess of 500 gal/min) have been constructed.

Precipitation on the valley floor and the surrounding mountains in the form of rain and snow is the source of recharge to the ground-water system. Streams crossing the valley lose significant quantities of water to the underlying material. Deep percolation of irrigation water (some of which is diverted from the Missouri River) and leakage from irrigation canals provide significant recharge during the irrigation season. Recharge from irrigation of lawns and from effluent of septic tanks also contributes to the ground-water supply, but this source is relatively minor.

Ground water moves generally toward Lake Helena (fig. 1), which is the natural point of ground-water discharge for the valley (Wilke and Coffin, 1973). Numerous domestic, stock, and irrigation wells located throughout the valley intercept part of the flow. Evapotranspiration, particularly in the northeastern part of the valley where ground-water levels are persistently high, accounts for a significant amount of water loss from the ground-water system.

Depth to ground water

Sewage effluent discharged from properly constructed septic tanks and soil-absorption systems should pass through a zone of unsaturated soil before entering the underlying saturated ground-water system. The oxygen present in the unsaturated zone provides some degree of protection to the ground-water system by oxidizing or decomposing some of the constituents in the sewage effluent. Health authorities commonly accept a minimum thickness of 4 feet of unsaturated material to obtain the optimum benefit of oxidation and decomposition. Because soil-absorption systems are commonly buried 2 feet below land surface, the City-County Health Department requires a minimum of 6 feet from land surface to the saturated zone for approval of a septic tank soil-absorption system (Will Selser, County Sanitarian, oral commun., 1979).

Although the approximate depth to ground water is known throughout the valley, the specific areas where the depth to ground water is less than 6 feet are difficult to delineate. The depth to ground water is often assumed to be the depth to water measured in wells. However, under confined (artesian) conditions, the depth to water in a well does not coincide with the depth to ground water.

Under confined conditions, an aquifer is overlain by a layer of material having less permeability than the aquifer. The water level in a well perforated in a confined aquifer stands at a level higher than the top of the aquifer. The water level in this instance coincides with the hydrostatic pressure level (potentiometric surface) in the aquifer. Conversely, water percolating from above may be trapped (perched) above the less permeable layer, in which instance the water level in a shallow well could be different than in a well completed in the confined aquifer.

Under unconfined conditions, significant confining layers are absent. In this instance, the water level in a shallow well that just penetrates the ground-water body coincides with the top of the water table. The water level in deeper wells may be higher or lower than in a shallower well depending upon whether the well is located in a discharge or recharge area.

Thus, water levels in the shallowest wells will provide the most accurate data to determine the depth to the saturated zone. In the absence of shallow wells, water-level measurements from deeper wells may be useful if the well construction is known and the hydrologic conditions are understood.

When one attempts to define a precise depth to water, for example a minimum of 6 feet for approving a septic system, the uncertainties involved need to be considered. Neither the land surface nor the water table are uniform in slope. Land-surface contours on U.S. Geological Survey 15-minute topographic maps of the valley have an interval of 40 feet. Between contours, an elevated or depressed area of as much as 40 feet may be present, but not be shown on the maps. Relief of this magnitude does not occur in the valley, but numerous areas with less relief such as old streambed channels do occur.

Local recharge and discharge patterns complicate the configuration of the water table. Irrigation ditches, for example, produce recharge mounds that persist through the irrigation season. Flood irrigation on croplands causes transient mounds that dissipate between flooding cycles. Drainage ditches in the low-lying parts of the valley artificially depress the water table. Pumping of large-capacity irrigation wells causes a local depression of water levels.

To refine earlier maps showing depth to water (Wilke and Johnson, 1978), water levels in test wells drilled during this project were measured periodically. Although these measurements provide additional control for estimating depth to water, the control is still limited to a finite number of data points. Where the depth to water is about 6 feet, hydrologic test pits are the best means for determining the precise depth to water at a specific site. The approximate minimum depth to water throughout the valley during 1976-79 is shown on plate 1. Although the map needs to be used with caution because of the uncertainties outlined above, it will be useful in determining the need for on-site test pits.

Water levels fluctuate seasonally in response to recharge. Hydrographs that show the water-level fluctuations in selected test wells for various areas of the valley are included on plate 1. The hydrographs illustrate both the magnitude and the timing of fluctuations. This information can be useful in evaluating water-level information from on-site test pits. By comparing a water level from a test pit with a hydrograph from a nearby test well, prediction of the seasonal high water level should be possible without requiring a full cycle of data. These hydrographs show only one season of fluctuation. During wetter or dryer years, the seasonal fluctuation may be more or less than during 1978-79.

Near the margins of the valley, the depth to water fluctuates seasonally as much as 15 feet. In lower lying areas, water levels fluctuate as little as 2 feet. The period of highest water level is directly related to the source of recharge. Water levels in most wells in the valley are highest in July or August in response to surface-water irrigation, but water levels in a few wells located near stream channels are highest during spring runoff. During the spring of 1975, excessive runoff caused widespread flooding in the valley and subsequent recharge to the water table. Flooded basements accompanied the unusually high water-table conditions resulting from this excessive runoff.

Distribution of fine-grained material

Helena Valley residents have long placed faith in the supposed existence of a continuous layer of fine-grained material that protects deeper aquifers from pollution by septic-tank effluent. Most wells in the Helena Valley penetrate varying thicknesses of silt and clay below the local water table, but above the sand and gravel aquifers in which the wells are completed. This "clay layer" or "hardpan" has been assumed to be an impermeable barrier through which sewage effluent or other pollutants could not pass.

The alluvial-type depositional history of the heterogeneous unconsolidated material makes the existence of an extensive and continuous layer of fine-grained material unlikely. Results of earth-resistivity surveys by Layne-Minnesota Co. and lithologic logs for three test wells drilled for the City of Helena in the southern part of the valley (R. A. Nisbet, City of Helena, written commun., 1979) indicate that relatively impermeable clay layers in the unconsolidated material are variable in thickness and extent. Furthermore, even the most fine-grained materials have some degree of permeability that would permit vertical migration of ground water under certain hydraulic-head conditions. Thus, there is little validity to the widespread belief that water from wells drilled to "second water" cannot be polluted.

If an extensive and continuous layer of fine-grained material underlies the valley, its presence should be evident from records of water wells. Drillers generally keep a record of the materials penetrated in drilling wells (well log), but the inconsistency of drillers' descriptions of materials makes interpretations difficult. What one driller might record as silty sand might be called clay, silty clay, or dirty sand by other drillers. The detail with which the record is kept, the type of drill used, and the driller's personal description of various lithologic units all contribute to inconsistency between logs. As a result, correlation of individual layers from one location to another on the basis of drillers' logs alone is tenuous.

To supplement the drillers' logs, about 60 gamma-ray geophysical logs were run in the test wells drilled during this study and in a few existing water wells and test holes. A gamma-ray log records the natural gamma radiation of the materials surrounding the well bore. Generally, in alluvial deposits, the primary source of natural gamma radiation is the radioactive isotope of potassium, potassium-40. During the weathering process, potassium-rich minerals are reduced to clay. The clay-rich deposits normally contain greater percentages of potassium than the adjacent sands or gravels and, consequently, emit more gamma radiation. A gamma-ray log can thus be used to distinguish between the fine-grained and coarse-grained layers.

More than 1,000 test borings were made by the U.S. Water and Power Resources Service (formerly U.S. Bureau of Reclamation) from 1949 to 1977 as part of a Helena Valley drainage investigation. Detailed, but unpublished, descriptions by geologists and soil scientists of the penetrated deposits were a valuable source of information defining the occurrence of fine-grained material at shallow depth. For their work, a zone was considered a barrier to percolation if the permeability was less than 20 percent of the weighted permeability of the materials above the zone (Glen Sanders, U.S. Water and Power Resources Service, oral commun., 1979). Most of the borings were less than 20 feet deep and located where potential drainage problems caused by shallow and relatively impermeable layers were anticipated. In general, those were areas where few people lived and for which no additional subsurface information was available.

The data obtained from drillers' logs of water wells, the drainage investigation, and the gamma-ray logs are summarized graphically on plate 2. The illustration shows the areas in which the uppermost "impermeable" layer was reported in the depth intervals 0-20 feet, 21-40 feet, 41-60 feet, 61-80 feet, or was absent above the total depth penetrated by the borings. Total depths of wells and test holes that reportedly did not penetrate a significant layer of fine-grained material are included to assist in evaluation of the information.

The illustration shows discontinuities, or "windows," in the fine-grained material through which water could migrate relatively unimpeded into the underlying aquifers. Even within the widespread 0-20-foot zone, the layers of fine-grained material are discontinuous. Because the distribution and quality of the data are not uniform, either laterally or vertically, the boundaries are not sufficiently defined to distinguish between areas suitable or unsuitable for soil-absorption systems.

Two lithologic sections (fig. 3) further illustrate the discontinuous nature of the fine-grained materials. In both sections the upper layers of fine-grained material appear to form fairly extensive lenticular bodies that would retard downward movement of water in the central part of the valley where water levels are normally near the land surface. Around the edges, in the areas of greatest residential development, the layers of fine-grained material are more discontinuous, and appear to represent lenses of relatively impermeable materials within an anisotropic unconfined aquifer. They would retard, but not necessarily prevent, downward movement of polluted shallow ground water into aquifers used for water supply.

AQUIFER TESTS

Aquifer tests were made at five widely spaced sites (pl. 1) during June 6-21, 1979, to obtain data describing the transmissivity and other properties of the aquifers. Observation wells were available for pumped wells 10N03W06ACD01 and 10N03W15DDD01. With the exception of well 10N03W15DDD01, knowledge of the lithology penetrated by the water wells and details of well construction were not available. In addition, the lengths of the aquifer tests were dependent on constraints by well owners and physical problems beyond the control of the investigators. Because of lack of knowledge about the lithology and degree of penetration of the aquifers by the well casing, and the necessarily short duration of the tests, complete quantitative analysis of the data was not justified. However, the results of the tests provide reasonable estimates of transmissivity as well as evidence that vertical drainage is induced or accelerated by pumping.

One well at each site was pumped for an extended period at a relatively constant rate of discharge. The resulting declines in the water levels in the pumped well and nearby observation wells were recorded at specific times. After the pump was stopped, water levels in the wells were monitored until near total recovery was recorded. The data from the tests are shown in a report by Moreland, Leonard, Reed, Clausen, and Wood (1979).

When a well is pumped at a constant rate, the water level in the pumping well declines as water is removed from the aquifer immediately surrounding the well. As pumping continues, the water levels in nearby wells normally decline, but at a slower rate than in the pumping well. The water surface connecting the wells forms an inverted cone of depression centered on the pumping well. The shape and rate of change of the cone of depression are used to determine the aquifer properties.

The transmissivity of the aquifer is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Values for each test were obtained by matching the time-drawdown curves plotted from the test data with type curves based on modifications of the original Theis nonequilibrium well formula (Theis, 1935). Most of the time-drawdown curves can be fitted to Theis curves, modified to reflect the effect of recharge or vertical drainage into the pumped aquifer. Best fits were obtained with type curves for nonsteady radial flow in an infinite leaky artesian aquifer after Cooper (1963, pl. 4) or delayed yield for unconfined anisotropic aquifers after Boulton (1963, fig. 1).

The Theis curve is based on the assumptions, among others, that (a) the water-bearing formation is homogeneous and isotropic, (b) the aquifer receives no recharge during the period of the test, and (c) the water removed from storage is discharged instantaneously with lowering of the hydraulic head. Unless these assumptions are met, the time-drawdown curves should not match the Theis type curve. The test results are consistent with the known geohydrology of the area as described above; that is, (a) the water-bearing formation is not uniform in permeability in either the horizontal or vertical direction, (b) recharge from the surface can enter the aquifer during a relatively short period of pumping, and (c) release of water from storage evidently is not instantaneous.

At most sites, the aquifers reacted during the early stages of pumping as would a confined aquifer in which pumpage is replaced almost instantaneously from storage by expansion of the water and compaction of the aquifer. Wellbore storage was negligible after the first minute of pumping. After about 10 to 30 minutes of pumping, the expanding cones of depression evidently intercepted additional sources of water, and drawdown was less than would be predicted from the Theis type curve. Where the source was a recharge boundary such as a

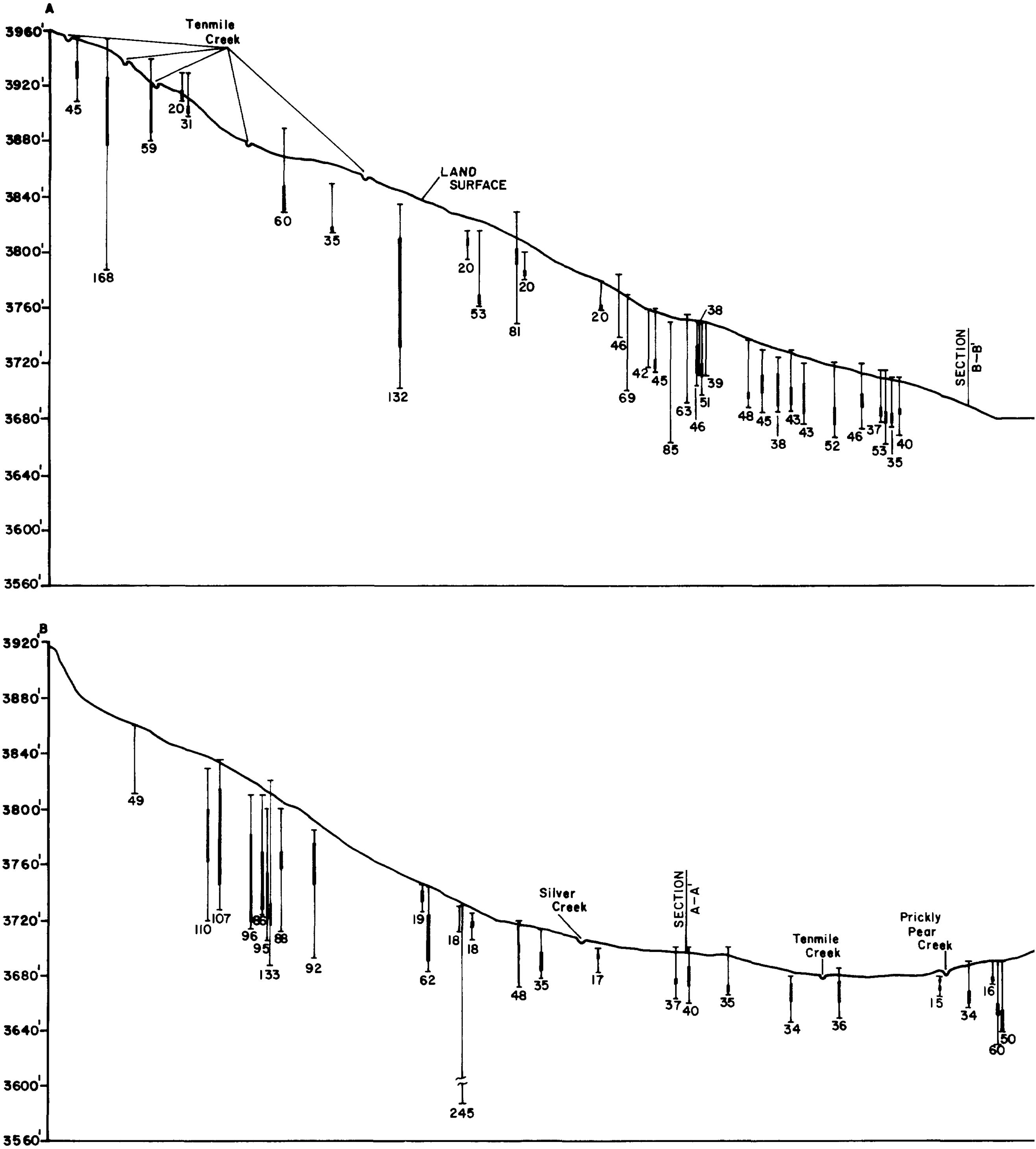
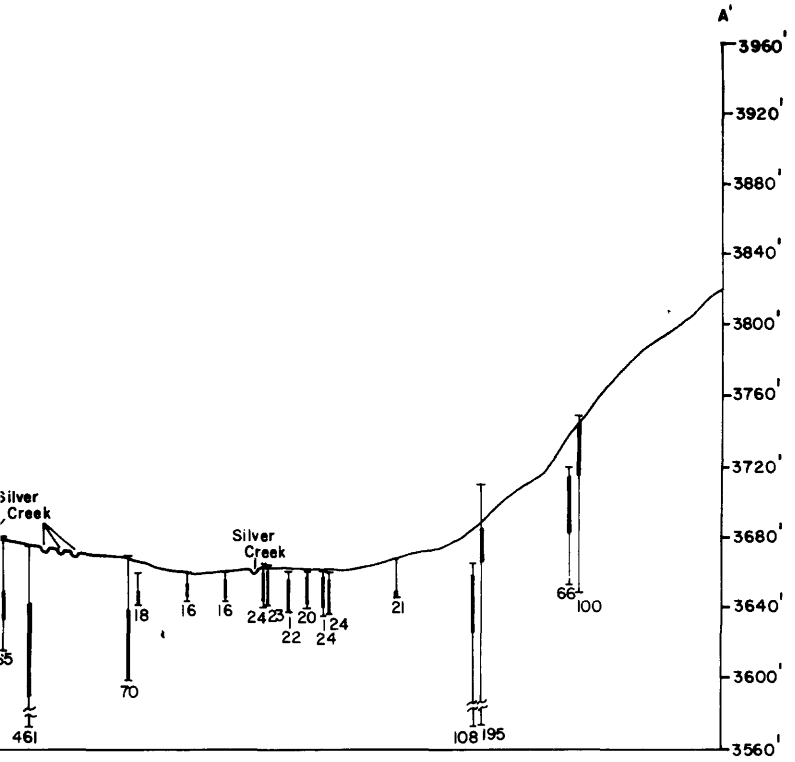


Figure 3.--Sections across Helena Valley showing intervals of fine-grained material ("clay") overlying principal shallow aquifers penetrated by water wells.



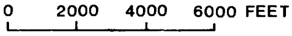
EXPLANATION

Water Well

Altitude of well sites and land surface estimated from map showing contour interval of 40 feet.

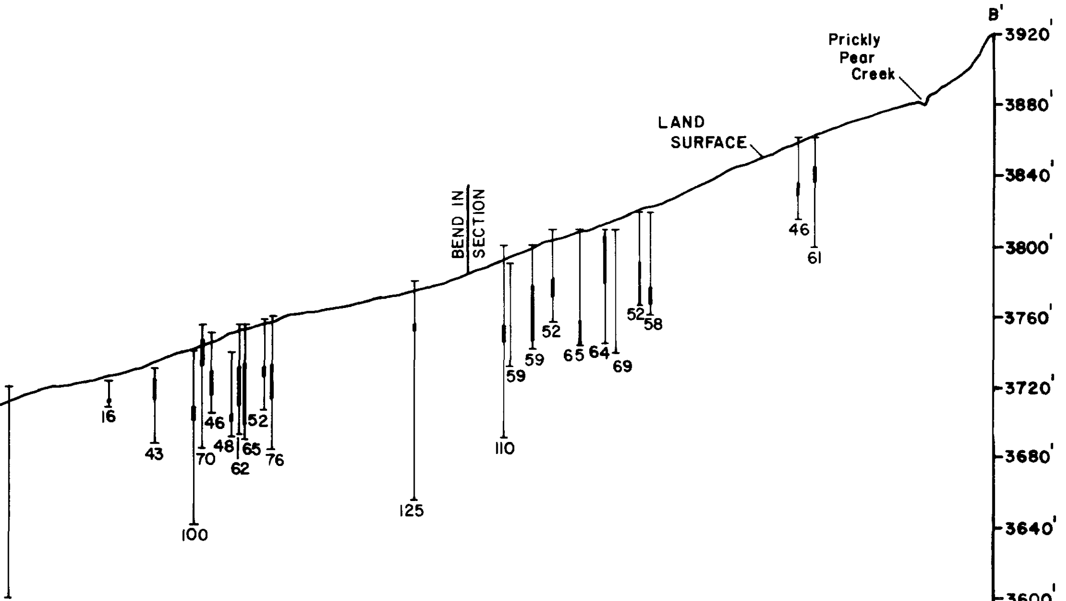
All wells are projected perpendicularly to the line of section, retaining original altitude

Line of section shown on plate 2



VERTICAL EXAGGERATION X50

NATIONAL GEODETIC VERTICAL DATUM OF 1929



surface-water body, the slope of the time-drawdown curves abruptly became almost horizontal. The diminished slope at most sites indicates vertical drainage of water into a continually expanding cone of depression. If so, the fine-grained layers known to overlie the aquifers apparently impede, but do not prevent, vertical movement of shallow ground water into the aquifer within the cone of depression.

An example of the aquifer tests is shown in figure 4. Well 10N03W06ACD01 was pumped at a rate of 604 gal/min and water levels were monitored in the pumping well and two observation wells. Observation well 10N03W06DBAA01 was installed 181 feet southwest of the pumping well; it was perforated in fine-grained material in the depth interval 32-34 feet. Observation well 10N03W06DBAA02 was installed 91 feet south of the pumping well; it penetrated fine-grained material in the depth intervals 45-50 feet and 52-57 feet below land surface and was perforated in coarse-grained material from 60 to 62 feet. The pumped well had a measured depth of 106 feet but the perforated interval was unknown.

The time-drawdown curves (fig. 4) for the pumped well and the near observation well are similar and can be matched to either delayed-yield or leaky artesian type curves. Values of transmissivity from the matched-curve technique were 9.3×10^3 ft^2/d for the aquifer penetrated by the pumped well and 8.0×10^3 ft^2/d for the aquifer penetrated by the near observation well. The

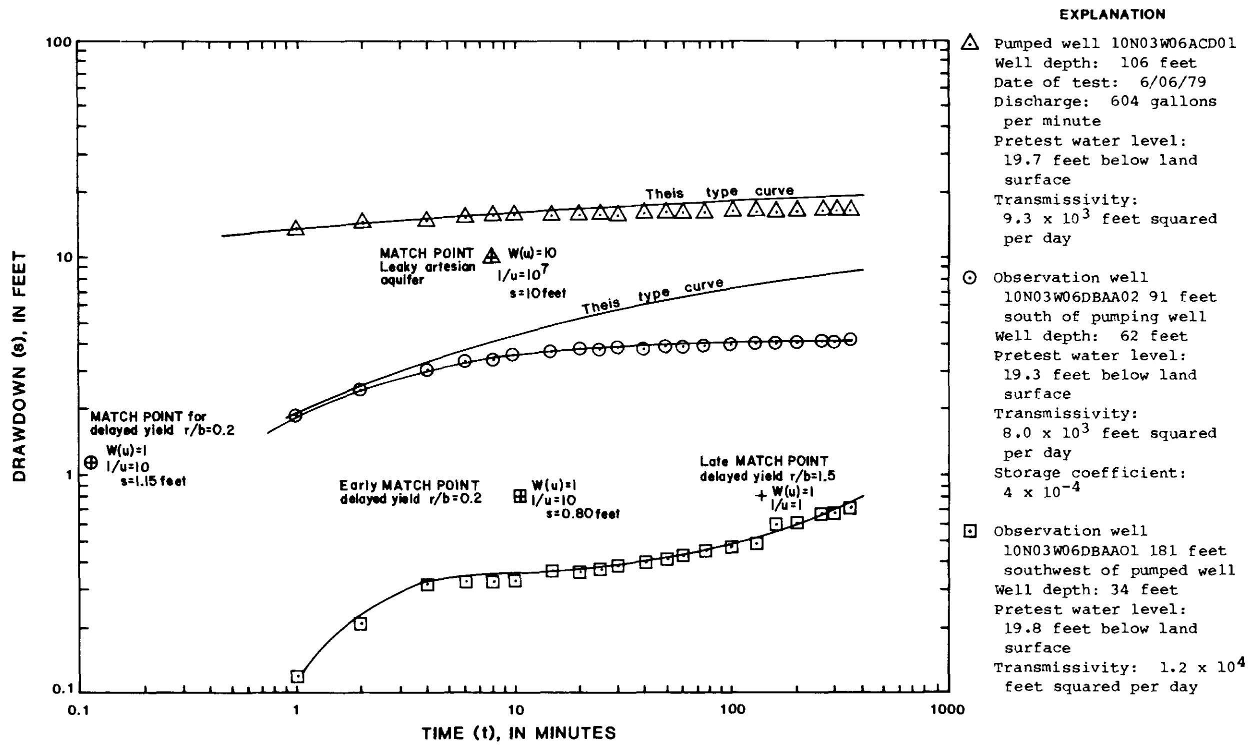


Figure 4.--Drawdown in pumped well 10N03W06ACD01 and observation wells 10N03W06DBAA01 and 10N03W06DBAA02.

coefficient of storage represented by the early phase of pumping was about 4×10^{-4}, within the range expected for a confined aquifer. Drawdown in the far observation well appears to fit a delayed-yield type curve. The drawdown in the far well indicates that downward percolation through the fine-grained material occurs in response to pumping from the underlying aquifer.

A transmissivity of about 1×10^4 ft^2/d represents a reasonable estimate for the alluvial aquifer penetrated by three of the pumped wells and is probably appropriate for the aquifer penetrated by most shallow wells in the more densely populated southern part of the valley. It probably is also applicable to estimates of the rate of lateral underflow.

For predicting the long-term effects of pumping on an unconfined or leaky aquifer system, pumping needs to be continued for at least 3 days. During the tests described in this report, none of the wells were pumped for more than 0.5 day. The tests were of sufficient duration, however, to indicate vertical movement of water into the cone of depression created by pumping. For delayed gravity drainage systems, the time-drawdown curve would steepen with extended pumping unless a recharge boundary were intercepted. As the source of gravity drainage is depleted, the time-drawdown curves would again conform to the Theis type curve.

The results of the tests appear to confirm the absence of a continuous, impermeable fine-grained confining layer overlying the alluvial aquifers in the valley. Longer aquifer tests under carefully controlled conditions are needed to more precisely evaluate the probability of delayed gravity drainage into the pumped aquifers.

Relatively large values of transmissivity normally are associated with broad cones of depression centered on the pumping well. Many potential sources of pollution (for example, soil-absorption systems) probably overlie the cones of depression created by pumping of water wells in the valley. Thus, prolonged pumping of wells similar to those tested probably would induce or accelerate vertical drainage of shallow ground water into the aquifers through or around discontinuous layers of fine-grained material. The estimated transmissivity of the unconsolidated material is about 1×10^4 ft^2/d. Where the water-table or potentiometric-surface gradient is 20 ft/mi (Wilke and Coffin, 1973), natural underflow through an area 1 mile wide would be 2×10^5 ft^3/d or 1,500,000 gal/d. The volume of effluent percolating into the aquifer from above would be much less than this and the effluent would be significantly diluted by underflow water moving laterally toward the well.

QUALITY OF GROUND WATER

Ground water contains dissolved chemicals derived from the rock and soil through which it moves. The amounts and kinds of dissolved chemical constituents depend, in part, on the chemical composition and solubility of the minerals in the rock and soil through which the water moves and the length of time the water is in contact with them. The more soluble the rock material, the more constituents the water can dissolve. Also, the longer the water is in contact with the rocks, the more minerals the water may dissolve.

The primary constituents found in most ground water in the Helena Valley are calcium (Ca^{+2}) and bicarbonate (HCO_3^-). These ions probably result from dissolution of limestone (mainly $CaCO_3$) and dolomite ($CaMg(CO_3)_2$) common in the bedrock surrounding the valley.

Magnesium (Mg^{+2}) and sulfate (SO_4^{-2}) are the next most common constituents in ground water in the Helena Valley. Magnesium occurs naturally in dolomite and in igneous rocks, both of which occur in the bedrock surrounding the valley. Sulfate commonly is derived from oxidation of pyrite and other sulfides common in the rocks.

Sodium (Na^+), potassium (K^+), and chloride (Cl^-) are the least abundant of the common ions in Helena Valley ground waters. These ions generally are abundant in more arid areas or in areas where sediments accumulated in sea water. Because sodium chloride is very soluble in water, it is readily flushed from the permeable soil and rock.

The relative abundance of the common ions in water samples from each well sampled during this study is shown graphically on plate 3. Calcium and bicarbonate are the predominant ions. The concentration of dissolved solids for most samples is less than 400 mg/L (milligrams per liter). However, the diagrams clearly show that Helena Valley ground waters vary considerably in the types and amounts of dissolved constituents.

If all ground water in the Helena Valley moved through the same rocks along similar paths of flow, all the well waters should be similar in quality. Based strictly on geology and ground-water flow paths, no explanation can be given for the occurrence of radically different water types, as illustrated by the water-quality diagrams on plate 3. Other factors obviously contribute to the water quality.

Many of the apparently anamolous analyses shown on plate 3 can be related to specific sources. For example, samples from several wells in sec. 18, T. 10 N., R. 3 W., contain more than 400 mg/L dissolved solids and have a chemical composition different than samples from most wells in other areas of the valley. This water is thought to contain sewage effluent from the city of Helena that was diverted into the placer mining operations in the Last Chance Gulch gravel deposits to float the dredge. In sec. 17, T. 10 N., R. 3 W., the relatively large concentration (936 mg/L) of dissolved solids in a sample from well 10N03W17ACAD01 probably is related to leaching of sludge and solid waste at the old landfill site near that location. The relatively large concentrations of dissolved solids, sodium, and chloride in samples from wells in sec. 16, T. 10 N., R. 3 W., may be related to leakage from sewage lagoons at the Helena municipal waste-water treatment facility.

At several sites, pairs of test wells were installed to monitor the quality of water in the near-surface aquifer and the underlying aquifers. Analyses of samples from the well pairs in secs. 1, 3, and 17, T. 10 N., R. 3 W., are similar, indicating little if any vertical variation in water quality. In contrast, analyses from pairs in secs. 21 and 30, T. 11 N., R. 3 W., and in sec. 5, T. 10 N., R. 3 W., show larger concentrations of dissolved constituents in water from the shallower well than from the deeper well. In sec. 9, T. 10 N., R. 3 W., the water from the deeper well contained larger concentrations of dissolved constituents than water from the shallower well. In some instances, differences may be attributable to improper sample collection, but mostly the differences indicate that the shallower ground waters have been altered by some activity of man. However, all the samples were of acceptable quality for drinking water with respect to the constituents and properties analyzed and measured.

On-site measurements

On-site measurements were made of specific conductance and nitrate in water samples from the test wells and from 98 domestic wells located throughout the valley. The results aid in definition of the areal distribution of water quality.

Specific conductance

Specific conductance is a measure of the capability of water to conduct an electrical current. It is directly related to the amount of dissolved constituents contained in the water. Although no unique relationship exists for waters containing different ratios and concentrations of ions, an empirical relation between specific conductance and the concentration of dissolved solids was developed for the study area. Within a range of specific conductance from about 200 to 1,500 µmho/cm (micromhos per centimeter at 25° Celsius), the concentration of dissolved solids can be estimated (fig. 5) using the linear equation:

$$DS = [0.65 \times SC] - 15 \qquad (1)$$

where DS = dissolved-solids concentration, in milligrams per liter; and

SC = specific conductance, in micromhos per centimeter at 25° Celsius

The range of values of specific conductance plotted on plate 4 illustrates the variability of water quality throughout the area. The data represent the aquifers from which most of the domestic supplies in the valley are obtained, although variations with depth generally are unknown.

Most wells on the east side of the valley contain water having a specific conductance of less than 400 µmho/cm (dissolved solids of less than 245 mg/L). Larger values of specific conductance in an area southeast of Lake Helena and northwest of the Helena Valley Regulating Reservoir probably are related to agricultural activities.

Specific conductance is larger in the southwestern part of the valley. In sec. 16, T. 10 N., R. 3 W., specific conductance greater than 1,600 µmho/cm was measured in water from a test well near the Helena municipal wastewater treatment facility. Another test well in sec. 17, T. 10 N., R. 3 W., yielded

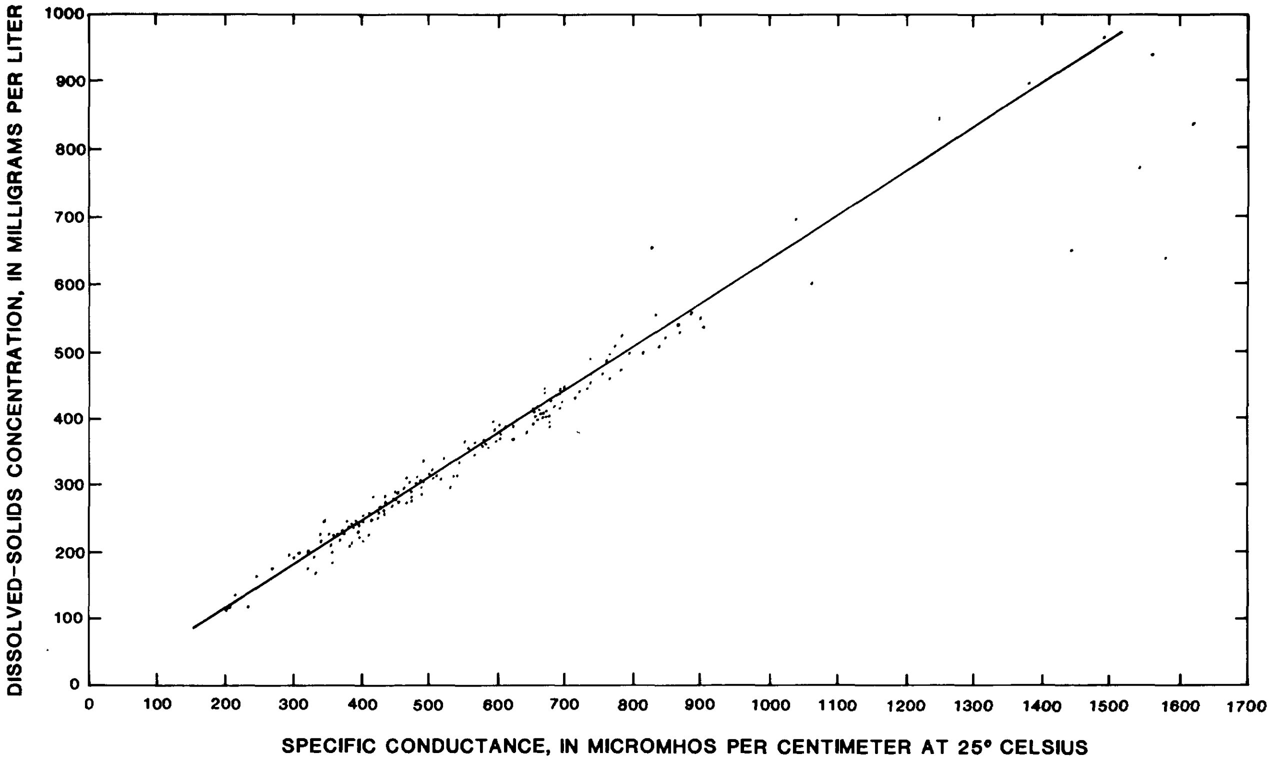


Figure 5.--Relation of specific conductance to dissolved solids in Helena Valley ground water.

a sample having a specific conductance of greater than 1,500 μmho/cm. This well is located near the old landfill site, which has recently been used as a burial site for sludge from the wastewater treatment facility. Other large values of specific conductance for samples collected in secs. 8, 17, and 18, T. 10 N., R. 3 W., probably are related to the dredge operations previously described. The specific conductance of water from several wells near the Scratchgravel solid waste disposal site in sec. 12, T. 10 N., R. 4 W., exceeds 600 μmho/cm. Leaching of waste is the probable cause of the large values.

Most of the samples from wells in the northwestern part of the valley had specific conductance in excess of 500 μmho/cm. Agricultural activity and domestic sewage from septic tanks probably are the sources of the larger than average values in this area.

Other isolated occurrences of larger than average specific conductance shown on plate 4 may be related to local agricultural activities. Insufficient data are available to determine the specific sources of the large values.

Nitrate concentrations

The concentration of nitrate (by convention expressed in milligrams per liter as nitrogen) commonly is used as an indicator of contamination from sewage effluent. Although sewage effluent normally contains more than 1 mg/L of nitrate, it is not the only source of nitrate in ground water. Pristine ground water generally contains less than 0.1 mg/L of nitrate. Where nitrate occurs in excess of 0.1 mg/L, some man-related activity is probably the cause.

Agricultural activities are commonly the source of nitrate in ground water. Plowing virgin land and replacing deep-rooted native vegetation with shallower-rooted crops can mobilize nitrate, which has historically been held in the soil zone. Excessive application of nitrogen-based fertilizers can contribute large amounts of nitrate to underlying ground waters. Animal wastes, particularly where concentrated in feedlots, corrals, or barnyards, can also contribute to the nitrate load.

The U.S. Environmental Protection Agency (1976) has placed a maximum allowable limit of 10 mg/L on nitrate in community water supplies. Studies have indicated that serious and occasionally fatal poisoning in infants has occurred following ingestion of well water containing more than 10 mg/L of nitrate. Although only infants appear to be susceptible to nitrate poisoning at this concentration, sufficient evidence exists to place the mandating limit on public water supplies.

The distribution of nitrate in samples collected during this study is shown on plate 5. Virtually all samples contained concentrations of nitrate in excess of 0.1 mg/L, but samples from only two test wells contained nitrate at concentrations exceeding the maximum limit of 10 mg/L. A sample collected on April 11, 1979, from test well 10N03W17ACAD01 located near the old landfill site, contained 52 mg/L of nitrate. A sample collected on January 19, 1979, from test well 10N03W11DDCC01 in a largely undeveloped area contained 12 mg/L of nitrate, but a sample collected on April 11, 1979, contained 1.2 mg/L. The largest concentration for a domestic well was 7.6 mg/L in a sample collected on June 7, 1979, from domestic well 11N03W17DDD01.

Ground water with relatively small values of specific conductance and nitrate concentrations greater than 1.0 mg/L underlies a broad area along the eastern edge of the study area. The small specific-conductance values and relatively large nitrate concentrations indicate that fertilizer leached by irrigation water having relatively small dissolved-solids concentrations is the major source of nitrates.

Concentrations of nearly 4 mg/L of nitrate in ground water from the eastern part of sec. 18, T. 10 N., R. 3 W., further substantiates the theory that sewage used in past dredging operations has degraded the ground water in that area. Much of the water underlying the northwestern part of the study area contains more than 1.0 mg/L of nitrate. Several representative samples (sec. 31, T. 11 N., R. 3 W., and sec. 24, T. 11 N., R. 4 W.) were from wells near residential developments where septic tanks may be major contributors to the nitrate concentrations.

Long-term water-quality changes

Several wells in the Helena Valley have been sampled periodically since about 1971 to monitor changes in water quality. Concentrations of chloride and nitrate and the specific conductance of samples collected between 1971 and 1979 are listed in table 1.

In general, the records indicate that water quality has not changed radically since 1971. The specific conductance of samples from all wells except one increased with time, but annual fluctuations generally exceed the long-term variations. The specific conductance of water from wells in sec. 18, T. 10 N., R. 3 W., generally increased from 1971 through 1976, then decreased gradually through 1979. Samples from well 10N03W08CDD01, downgradient from these wells, show a continual gradual increase. The data indicate that a plume of degraded water near the old dredging operations is slowly moving northeast from section 18. Concentrations of nitrate and chloride show similar patterns.

The wells for which long-term records are available are all located in the western part of the study area and do not represent the overall water quality in the Helena Valley. Most were selected to monitor the movement of degraded water near the dredging operations. A broader network of wells would be needed to monitor changes throughout the valley.

A network of wells equally spaced throughout the valley could be sampled periodically for specific conductance and nitrate to more accurately evaluate long-term ground-water-quality changes. If significant changes in specific conductance or concentrations of nitrate were noted, more complete analyses would be justified.

SUMMARY

The Helena Valley is underlain by a thick accumulation of unconsolidated clay, silt, sand, and gravel. The coarser-grained material is the source of domestic water supplies for nearly 5,000 valley residents.

Most domestic wells in the valley are drilled through at least one layer of fine-grained material to obtain adequate yield and to avoid the potentially contaminated water in the shallowest aquifers. The layers of fine-grained material do not appear to form a continuous layer over the underlying aquifers. In parts of the valley, no layers of fine-grained material were penetrated by wells or test holes to the depths drilled. Where layers of fine-grained material were penetrated, the layers are discontinuous.

Depth to ground water varies seasonally throughout the valley. The magnitude and timing of the seasonal fluctuations are dependent upon the source of recharge. In most of the valley, water levels are highest in July or August in response to widespread irrigation. Highest water levels in a few wells located near stream channels occur during the spring in response to snowmelt runoff. High water-table conditions characterize a broad area in the northeastern part of the valley. The map showing depth to water is considered to

Table 1.--Selected chemical constituents in water from monitored wells

Well number	Date	Chloride (milligrams per liter)	Nitrite plus nitrate as N (milligrams per liter)	Specific conductance (micromhos per centimeter at 25° Celsius)
11N03W31DAD01	12-18-72	9.1	1.0	554
	08-23-73	8.6	.96	565
	12-03-74	9.4	.92	570
	01-21-76	5.8	1.0	575
	06-13-77	7.9	.5	[a]575
11N03W31DDA01	09-01-71	7.2	1.0	556
	12-18-72	10	1.2	555
	08-23-73	8.9	1.1	566
	12-03-74	9.3	.97	578
	01-21-76	5.6	1.2	577
	06-13-77	8.1	.90	[a]584
	11-06-78	4.4	[b]1.0	569
	02-20-79	10	[b].96	582
10N03W05ABA01	08-17-71	6.8	.9	418
	12-18-72	7.7	.8	435
	08-23-73	7.0	.67	430
	06-13-77	7.8	.75	[a]448
	11-06-78	6.8	[b].88	426
	02-13-79	7.7	[b].63	436
10N03W06ACD01	08-18-71	6.4	.4	487
	12-18-72	9.0	.4	503
	08-23-73	8.4	.44	506
	12-03-74	8.5	.33	507
	01-21-76	5.8	.41	496
	06-13-77	9.1	.63	[a]530
	11-06-78	9.1	[b].50	502
	02-13-79	11	[b].64	505
10N03W08BBA01	08-24-71	7.1	1.1	409
	12-18-72	10	1.4	439
	08-23-73	9.5	.83	450
	01-21-76	11	2.1	471
	06-13-77	8.8	1.4	[a]470
	11-06-78	13	[b]1.9	491
	02-13-79	10	[b]1.4	454
10N03W08CDD01	08-24-71	19	1.8	607
	12-18-72	22	1.6	641
	08-23-73	24	1.9	650
	12-03-74	22	1.3	636
	01-21-76	22	2.2	651
	06-13-77	23	2.9	[a]675
	11-06-78	27	[b]3.9	671
	02-13-79	28	[b]3.8	672

Table 1.--Selected chemical constituents in water from monitored wells--Continued

Well number	Date	Chloride (milligrams per liter)	Nitrite plus nitrate as N (milligrams per liter)	Specific conductance (micromhos per centimeter at 25° Celsius)
10N03W18ACC01	08-23-71	11	.59	528
	12-18-72	21	1.4	842
	12-03-74	20	1.5	883
	01-21-76	16	1.4	618
	06-13-77	23	1.1	[a]572
	02-13-79	19	[b]1.1	586
10N03W18ADA01	01-24-73	--	5.1	--
	08-23-73	29	4.2	734
	12-03-74	26	2.6	752
	01-21-76	25	2.8	821
	06-13-77	25	4.5	[a]820
	02-13-79	22	[b]3.7	755
10N03W18ADA02	05-19-70	23	8.0	691
	08-24-71	24	6.3	636
	12-18-72	29	15	792
	01-24-73	--	15	--
	07-05-73	22	2.4	--
	12-03-74	25	2.4	837
	01-21-76	25	2.8	862
	06-13-77	24	3.9	[a]830
	11-06-78	21	[b]4.8	781
	02-20-79	20	[b]3.5	737
10N03W18BAA01	08-23-71	25	1.3	708
	12-18-72	22	1.1	711
	12-03-74	21	1.9	667
	01-21-76	27	2.2	720
	06-13-77	34	1.7	[a]822
	11-06-78	21	[b]2.1	647
	02-13-79	25	[b]1.3	654

[a] On-site determination
[b] Nitrate only

be only a useful approximation. Test pits or borings are the only source of precise information on depth to water at specific sites.

Aquifer tests of selected wells in the valley indicate that the transmissivity of the unconsolidated material is about 1 x 10^4 ft^2/d. Using a water-table or potentiometric-surface gradient of 20 ft/mi, underflow through an area 1 mile wide is about 2 x 10^5 ft^3/d or 1,500,000 gal/d.

The aquifer tests indicate that the aquifers are overlain by leaky confining layers. A large-capacity well or a well field can be expected to produce a cone of depression that would induce downward migration of water through the leaky confining layer. However, if the pumping rate is relatively small, and the transmissivity of the aquifer is as much as 1 x 10^4 ft^2/day, water percolating into the aquifer from above should be significantly diluted by deeper water moving laterally toward the well.

Water quality in the aquifers underlying the valley is variable but is generally acceptable for domestic use. The water is primarily calcium bicarbonate type water containing about 400 mg/L of dissolved solids. Nitrate concentrations of water samples from domestic and test wells ranged from about 0.1 to 52 mg/L but were generally less than 2.0 mg/L. Although long-term records of water quality are available for only part of the study area, the data indicate that water quality has not changed radically since 1971. Monitored wells near the old dredging operations show that a plume of degraded water is slowly moving northeast from sec. 18, T. 10 N., R. 3 W. This study reveals the impacts of man's activities on ground-water quality in many parts of the valley. It also indicates that a network of wells throughout the valley could be used to more accurately evaluate long-term water-quality changes.

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