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GROUND-WATER CONTAMINATION IN THE ROCKY MOUNTAIN ARSENAL AREA, DENVER, COLORADO

Abstract: Improper waste-disposal practices at the Rocky Mountain Arsenal have seriously damaged the free ground-water aquifer throughout an area of approximately 6½ square miles. Contaminants include chlorates and 2,4-D-type compounds, both of which are effective herbicides. Contaminated ground water within the affected area is toxic to agricultural crops and unpotable for humans. Corrective measures have been taken to halt further contamination, but the area of toxicity is expanding owing to migration of the body of ground water already contaminated.

Since 1943, chemical factories at the Rocky Mountain Arsenal, northeast of Denver, Colorado (Fig. 1), have manufactured materials for chemical warfare and other chemical products. Between 1943 and 1957, waste products from these operations were dumped into artificial reservoirs that were located above the water table and separated from it by permeable sediments. When the reservoirs were constructed no attempt was made to seal them, and consequently conditions favored infiltration of the waste water into the subsurface throughout the 14 years that the reservoirs were used as waste basins.

These waste-disposal practices have seriously contaminated the underlying free ground-water aquifer in a large area that extends northwest from the waste basins. This aquifer, because it is highly permeable and can be penetrated at a shallow depth, is used extensively as a source of water for domestic and livestock use. In addition, it is the only aquifer in the area that can yield the large quantities of water needed for irrigation purposes. Owing to contamination from the Arsenal, however, approximately 6½ square miles of this aquifer now contains ground water that generally is toxic to plants, unpotable for humans, and apparently injurious to livestock.

Alternate supplies of water are not readily accessible in the area. Good-quality ground water in quantities adequate for domestic and livestock use can be obtained from deep bedrock aquifers, but many residents in the affected area do not have deep wells, and the high cost of new wells has forced many of these residents to import water. Furthermore, the deep bedrock aquifers are not permeable enough to supply the large quantities of water that are needed for irrigation purposes. Irrigation ditches traverse the affected area, but, because farmers here have low priorities on ditch water, this source of water is inadequate; since no other source of irrigation water is available, the farmers have been forced to decrease the number of acres they cultivate.

Contamination of the ground-water supplies has caused decline in property values. Qualified land appraisers have estimated that, owing solely to the loss of usable ground water, land formerly valued at $500 per acre now is worth only $250 per acre. Additional damage also has resulted from continued crop loss owing to prolonged retention of the toxic substances by soils. In some places, land that was irrigated with toxic water in 1954 did not yield normal crops in 1960, although toxic water has not been applied to the soil since the initial irrigation in 1954.

Arsenal authorities first became aware of the problem in 1954, and in 1955 measures were taken to halt further contamination of the aquifer. The volume of waste produced by Arsenal operations was greatly reduced, and a reservoir with an asphalt-sealed bottom was constructed for waste disposal. This reservoir, which was completed in 1957, has received all the waste produced since that time. Plans also are in progress for construction of a well 10,000 to 12,000 feet deep that will permit injection of the waste water into deep bedrock formations that cannot be used for water supplies. It is hoped that these corrective measures will prevent further contamination of the shallow aquifer. However, extensive damage already has occurred; the front of the toxic ground water has migrated 5 miles from the waste basins, and continued migration can be anticipated.

Investigation of this problem began in June

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1954, when a complaint of crop damage was made to Arsenal authorities by Mr. Jesse E. Powers, owner of a farm located northwest of the Arsenal boundary (Fig. 2). Since that time various aspects of the problem have been investigated by private consultants, university research groups, and several government agencies, including the U. S. Geological Survey (Petri and Smith, 1956). This paper summarizes the hydrogeologic aspects of an investigation of the problem that was carried on by three members of the University of Colorado faculty between 1956 and 1960. Three aspects of the problem were investigated in the study: (1) a botanical and chemical phase for the purpose of identifying the phytotoxic materials (those poisonous to plants) in the ground water; (2) a chemical and botanical phase to determine methods of removing or neutralizing the phytotoxic substances; (3) a geologic phase to determine the path of migration of water seeping into the subsurface from the Arsenal waste basins, and its relationship to areas of phytotoxic ground water northwest of the Arsenal. The botanical research was directed by Dr. Erik Bonde of the Biology department,

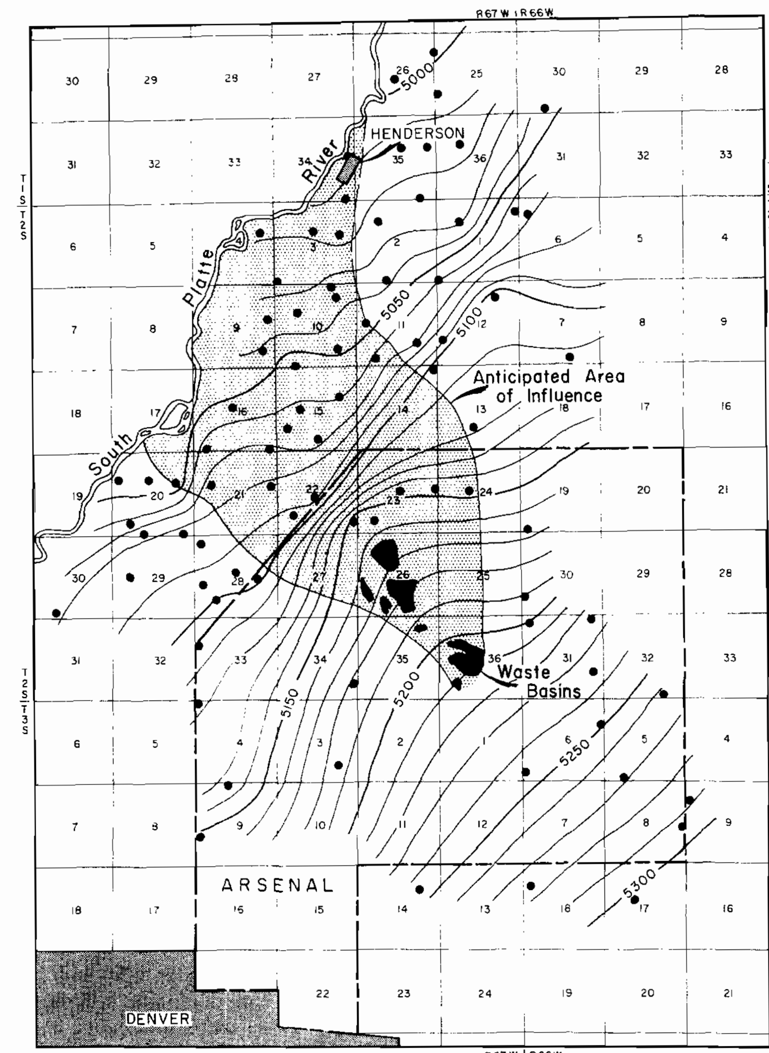

Figure 1. Water-Table Contours for April 1956. Showing anticipated area of influence of Arsenal waste basins. Water-table elevations at control points are taken from Petri and Smith (1956).

the chemical research by Dr. Paul Urone of the Chemistry department. The details of the results of these phases of the investigation will be published separately. The geologic phase was the responsibility of the writer, and the results of that study are presented here.

The Arsenal, including the area in the vicinity of the waste basins, is underlain by permeable surficial deposits consisting of upland alluvium and eolian sand and silt of Pleistocene and Recent age. These deposits in turn are underlain by bedrock sediments composed of poorly consolidated sandstone, siltstone, conglomerate, and mudstone of Cretaceous and Tertiary age. Regardless of age, all the interconnected permeable sediments above the highest continuous bed of impermeable material behave as a hydrologic unit and contain free ground water that migrates under the influence of the water-table gradient. These permeable sediments have a maximum thickness of about 75 feet and an average thickness of about 40 feet, the lower part of which is saturated and forms the shallow aquifer in the area. Owing to relief on the bedrock surface the thickness of the saturated zone ranges from 0 to about 50 feet.

At present ground-water contamination generally is limited to this shallow aquifer. Deeper bedrock aquifers occur in the area, but these contain confined ground water that is separated from the contaminated water by impermeable clay layers. These aquifers have been contaminated only where old wells have been abandoned, or where damaged or improperly sealed well casings have locally permitted infiltration of the toxic water through the confining layers.

The configuration of the water table (Fig. 1) indicates that ground water migrates beneath the Arsenal waste basins in a generally northwest direction toward the South Platte River valley. These data indicate that any water recharged to the aquifer from the waste basins also will migrate northwestward. The area affected by such recharge should lie generally within the anticipated area of influence shown on the map, the boundaries of which have been determined by constructing lines that originate at the edge of the waste basins and extend in a downslope direction perpendicular to the water-table contours. The actual area of influence of the Arsenal waste basins, however, can be expected to vary somewhat from the anticipated area shown in Figure 1 because local inaccuracies may exist in the interpolated positions of the water-table contours, and because lateral diffusion may carry some of the dissolved toxic materials beyond the borders of the anticipated area. Nevertheless, in a general way the migration of water that seeps into the subsurface from the waste basins should follow the path outlined (Fig. 1).

That the predicted migration has occurred is evident from Figure 2, which shows a striking correlation between the anticipated area of influence of the waste basins and the actual area of phytotoxic ground water. The boundary of the latter has been determined from data collected in the botanical phase of the study in which water samples from selected wells throughout the area were used to irrigate test plants grown in University greenhouses. The boundary is generalized, but it reasonably delineates the area that presently contains phytotoxic ground water, and it shows the direction toward which the contaminated water is moving, where additional crop damage may occur in the future if irrigation with ground water is continued.

The ground water is not consistently phytotoxic everywhere within the affected area. Water from some wells has not caused plant damage in the greenhouse experiments, and water from other wells has caused plant damage in some experiments and produced normal plant growth in others. These differences in toxicity from place to place and from time to time are caused in part by variations in the permeability of the sediments and in part by variations in the amount of dilution by uncontaminated recharge from such sources as rainfall, irrigation ditches, and underflow in the South Platte alluvium. In spite of these local variations in toxicity, however, the evidence indicates that ground water in the shallow aquifer is potentially toxic to plants throughout the area shown to be phytotoxic in Figure 2, and plant damage can be expected wherever this water is used for irrigation.

Studies made in the chemical and botanical phases of the investigation have determined that at least two phytotoxic substances are present in the contaminated water. Each toxicant tends to be concentrated in a separate part of the contaminated area (Fig. 2), and each is related to a separate type of industrial effluent. In the area farthest from the Arsenal waste basins, the phytotoxicity is caused by dissolved chlorate, and is related to waste products that were dumped into the basins between 1944 and 1950 (Weintraub, 1959, p. 4–6). These waste products have not recently been a part of the industrial effluent. The migration front of this type of toxic ground water lies about 5 miles from the waste basins, and the total area presently affected is about 3 square miles. Nearer toxicity has migrated about 3½ miles from the basins and has contaminated an area of about 3½ square miles, making a combined area of about 6½ square miles that is underlain by generally phytotoxic ground water.

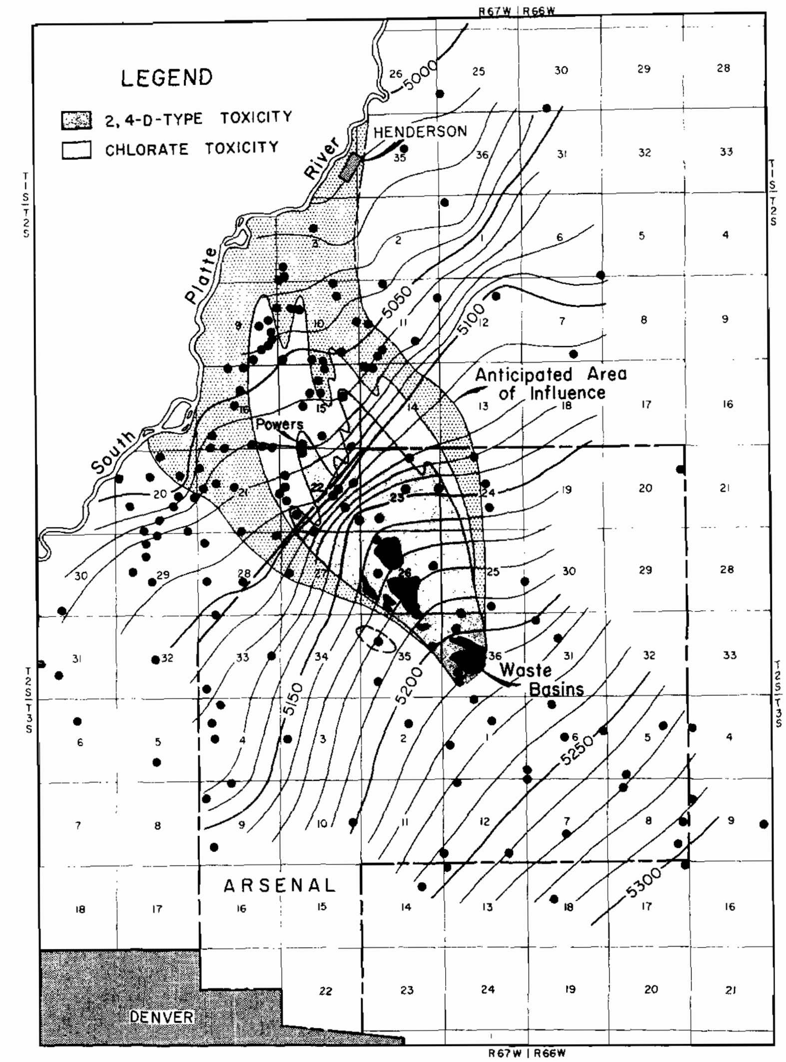

Figure 2. Areas of Generally Phytotoxic Ground Water. Control points show locations of samples tested in greenhouse experiments.

the waste basins the phytotoxicity is caused by either 2,4-dichlorophenoxyacetic acid (2,4-D) or a closely related compound and is related to wastes produced at the Arsenal since 1950 (Weintraub, 1959, p. 8–10). At the time of this writing, ground water containing 2,4-D-type

Available Arsenal records indicate that chlorates and 2,4-D-type compounds were at no time direct waste products of any of the Arsenal operations. These toxicants appear to have originated as a result of chemical reactions that occurred within the waste basins where effluent from different types of operations became mixed.

The present body of phytotoxic ground water will probably continue to move in the direction of the water-table gradient, and the area of toxicity will continue to expand. The configuration of the water-table contours and the shape of the west boundary of the phytotoxic area shown in Figure 2 indicate that the direction of ground-water migration changes from northwest to northeast as the water moves into the alluvium of the South Platte River valley. Hence future expansion of the phytotoxic area can be expected in a northeast direction within the South Platte River valley, toward the town of Henderson. In addition, continued expansion may eventually carry the toxicants into the surface water of the South Platte River, but dilution here will probably be great enough to prevent the river water from becoming phytotoxic.

The rate of migration of the front of the body of phytotoxic water is governed by permeability of the aquifer, water-table gradient, amount of recharge of phytotoxic materials, and amount of dilution by uncontaminated water. Because these are variable factors, the migration rate of the front is not the same everywhere. Based on the time required for the phytotoxic waste water to reach control points in the affected area, the maximum migration rate along the front is estimated to be less than 3 feet per day. The initial migration of the chlorate front across the area between the waste basins and the Powers farm (Fig. 2) was at a rate of approximately 3 feet per day, and the front of the area of 2,4-D-type toxicity migrated across the same area at a similar rate. The present migration rate of the phytotoxic front, however, probably is somewhat slower than when the front was near the Powers farm because of the increased tendency for dilution along the more extended front, and because recharge of significant amounts of chlorates to the aquifer has been eliminated since 1950.

The front of the area of 2,4-D-type toxicity steadily is encroaching upon the area of chlorate toxicity, and some wells that formerly yielded chlorate water now yield water that causes 2,4-D-type damage to plants. This encroachment probably will continue, but whether or not the 2,4-D front will eventually overtake the more slowly moving chlorate front is problematical.

The extent of the area that ultimately will be affected by phytotoxic ground water will depend in part on the amount of dilution needed to reduce both the chlorate and 2,4-D-type toxicants to nontoxic concentrations, and in part on how effectively the asphalt membrane in the bottom of the present waste basin prevents further recharge of the toxicants. Assuming that the source of contamination has been effectively sealed, the concentration of the contaminants at the toxic front eventually will reach nontoxic levels owing to mixing with uncontaminated water, and expansion of the phytotoxic area will cease. Adequate dilution, however, may not occur until the fronts of both types of phytotoxic ground water have migrated to the South Platte River. Meanwhile, the toxicity of the entire body of contaminated water should gradually decrease owing to dilution by continued recharge from uncontaminated surface sources such as rainfall and irrigation ditches and from the uncontaminated underflow in the South Platte alluvium. The time necessary to dilute the phytotoxic water effectively, however, is not known. It will probably take many years to dilute all the water in the affected area to the extent that it will be consistently safe for use, because chlorate and 2,4-D are toxic to plants in concentrations of only a few parts per million, and both substances appear to be chemically stable under the natural conditions in the aquifer.

Restoration of the normal ground-water quality in the affected area will be aided by any measure that will help to speed natural dilution, such as excessive irrigation of the area with uncontaminated surface water. At present, however, excessive irrigation does not seem practicable because in the affected area the existing supplies of uncontaminated water from both surface and subsurface sources are inadequate even for normal needs. Moreover, it is unlikely that additional water can be imported into the area because all available surface water in this semiarid region has been previously allocated to other uses.

Possibly the existing toxicity also could be diminished by artificially recharging the aquifer with a neutralizing agent, but as yet no safe and economical substance has been determined.

This study provides a noteworthy example of the damage that results to ground-water supplies from improper methods of industrial waste disposal. Furthermore, it typifies a commonplace problem. The use of basins for waste-disposal purposes is common practice, but there is wisdom in such practice only if infiltration of contaminated water into usable aquifers can be effectively prevented. Where unsealed waste basins containing toxic waters are located on permeable material, as at the Rocky Mountain Arsenal, they serve the unintended function of infiltration basins that provide local sources of contaminated recharge. Damage to the aquifer becomes inevitable because the soluble toxic compounds readily pass through soils into the underlying ground water. Once these compounds are present in ground water they are difficult to remove; natural dilution is slow, and treatment or artificial flushing generally is impractical. Moreover, because the rate of ground-water migration generally is slow, large areas may be affected before the damage is detected, and many years may be required before the aquifer can be restored to its normal quality.

The only reasonable cure for such problems is the prevention of contamination. This requires knowledge of the hydrogeologic conditions at proposed sites of waste-disposal basins. With adequate investigation, problems such as those that now exist near the Rocky Mountain Arsenal are readily anticipated before they occur, and measures can be taken to avoid them.

Acknowledgments

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