Future Development of the Ground-Water Resource in the Lower Great Miami River Valley, Ohio—Problems and Alternative Solutions

GEOLOGICAL SURVEY PROFESSIONAL PAPER 605-D

Prepared in cooperation with the Miami Conservancy District and the Ohio Department of Natural Resources, Division of Water, Columbus, Ohio

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By ANDREW M. SPIEKER

GROUND WATER IN THE LOWER GREAT MIAMI RIVER VALLEY, OHIO

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By Andrew M. Spieker

ABSTRACT

The valley-train sand and gravel aquifers of the Great Miami River valley below Dayton, Ohio, can be expected to yield an initial withdrawal of 300 million gallons per day—nearly three times their present rate of pumpage of 110 million gallons per day—provided that future developments are sufficiently distant from the present pumping centers. Most of the used ground water is returned to the river as sewage and could be recycled as induced recharge to the aquifers. This recycling would increase the total potential yield of the aquifers to much more than the initial withdrawal yield. The only limit on this recycling would be imposed by deterioration of quality of the used water or by the cost of treatment necessary to maintain adequate quality.

Probably the greatest future problems will be declining ground-water levels and local overdraft, both resulting from increased water use, ground-water contamination, and the aplication of existing law to situations involving water rights. Overdraft can best be avoided by careful spacing of future ground-water developments and location of these supplies in favorable hydrogeologic environments. Reuse of water by industry is an alternative to developing new supplies, for it can materially reduce water consumption. Ground-water contamination, most of which is derived from water induced from streams by pumping, can best be controlled by maintaining water of good quality in the streams. Plans for management of the ground-water resource should include careful consideration of the close interrelation of surface water and ground water.

INTRODUCTION

PURPOSE OF REPORT

This report is the final chapter in a series dealing with the ground-water resource in the lower Great Miami River valley. In planning the investigation it was decided that the overall report would be more useful if it were oriented toward specific ground-water problems. Thus, each preceding chapter in this series deals with a definite aspect of the occurrence of ground water in this area, and this chapter provides a summary

Four ground-water problems of particular importance were identified: (1) variable availability of water in place and time, (2) local overdraft and declining ground-water levels resulting from increased water use, (3) ground-water contamination, and (4) water-rights law. Chapters A, B, and C provide the hydrogeologic framework necessary for dealing with these problems. Chapter A (Spieker, 1968) deals with the occurrence of ground water in relation to its natural environment, the distribution of water in place and time, pumpage of ground water, and chemical quality of ground water; chapter B (Watkins and Spieker,[1]) will cover geophysical and geological interpretation of seismic refraction surveys conducted to determine the extent and the configuration of the area's buried interglacial valleys; and chapter C (Spieker, 1968) describes an analog-model study of the Fairfield-New Baltimore area, where the city of Cincinnati has proposed the development of a large ground-water supply. Chapter D (the present report) defines existing and anticipated hydrologic, socio-economic, and legal problems connected with the future development of the ground-water resources of the lower Great Miami River valley.

COOPERATION AND ACKNOWLEDGMENTS

This report was prepared by the U.S. Geological Survey in cooperation with the Miami Conservancy District, Max L. Mitchell, chief engineer, and the Ohio Department of Natural Resources, Division of Water, C.V. Youngquist, chief. The project was supervised by Stanley E. Norris, district geologist of the U.S. Geological Survey's Ground Water Branch in Ohio, under the general direction of the Ohio Water Resources Division Council.

A list of representatives of industry and municipalities who assisted in the completion of the investigation by providing data and access to their facilities appears in the first chapter of the series. In connection with the present chapter, the author expresses his appreciation to Messrs. J. E. Barker, R. L. Bookwalter, R. V. Getter, and H. F. Hansell of Armco Steel Corp. for

[1] Report in preparation.

their cooperation in furnishing the data on which the discussion of ground-water problems at the Armco East Works is based. Charles M. Bolton, Superintendent of the Cincinnati Water Works, Harold F. Augenstein, Superintendent of the Hamilton Water Works, and Robert C. Lewis, General Manager of the Southwestern Ohio Water Co., were most cooperative in providing the author with data. The material pertaining to the water-rights law in Ohio is based largely on research by George D. Dove, formerly with the U.S. Geological Survey.

GROUND-WATER PROBLEMS

VARIABLE AVAILABILITY OF WATER

The most general and basic problem regarding development of the ground-water resources of the lower Great Miami River valley arises from variations in the availability and distribution of water with respect to place and time. These variations are discussed in some detail in chapter A (Spieker, 1968a) of the present series and will be only briefly summarized here. Also in chapter A, the area has been classified into 11 hydrogeologic environments on the basis of hydrologic and geologic factors affecting the ability of each part of the area to sustain the development of large ground-water supplies. The key factor, then, is the availability (or the lack) of water for recharge by induced stream infiltration. Figure 1 is a generalized map of the area simplified from the more detailed map in chapter A. It shows those parts of the study area most favorable for the development of large ground-water supplies owing to the availability of stream water for induced recharge; those parts less favorable for large supplies owing to the lack of available water for induced recharge; those areas of existing ground-water development; and one area where local overdraft is a problem.

The existing centers of pumping are mainly in and around the area's major cities, and the only area of chronic overdraft is southeast of Middletown. The areas most favorable for the development of large ground-water supplies are between West Carrollton and Miamisburg, between Franklin and Middletown, in the vicinity of Trenton, between Fairfield and Ross, southwest of New Baltimore, and in the lower Whitewater River valley south of Harrison. The last-mentioned area has the greatest untapped ground-water potential of any part of the lower Great Miami River valley.

Variations in the storage of ground water with respect to time are best expressed by a hydrograph, or a graph showing fluctuations in the elevation of the water surface which reflect changes in storage in the aquifer. Figure 2 is the hydrograph of observation well Bu-7, which is in the Hamilton South well field. The fluctuations shown by this graph are typical of those observed in the valley-train aquifers of the lower Great Miami River valley. An annual cyclic fluctuation of 8–10 feet, caused by recharge during the winter and spring and by discharge during the summer and fall, is observed. Since 1956 the Hamilton South well field has been pumping an average of 7.5 mgd (million gallons per day). This pumping has caused a lowering of the water surface of about 4 feet and has slightly accentuated the peaks of the hydrograph (fig. 2) but has caused no persistent downward trend. The cone of depression appears to have become stabilized fairly soon after pumping started. Such an absence of any persistent downward trend indicates that the hydrologic system in this area is capable of sustaining pumping at the existing rate. The next section considers water-level fluctuations in a part of the area where the aquifer has been subjected to long-term overdraft.

LOCAL OVERDRAFT AND DECLINING GROUND-WATER LEVELS

Total ground-water pumpage in the lower Great Miami River valley in 1964 is estimated to have been 110 mgd, mostly concentrated in and around the larger cities, as indicated in figure 1. Historical records are not sufficiently complete to show just how fast the amount of ground-water pumpage has increased in the area; however, pumpage is estimated to have approximately doubled from the beginning of World War II to 1964, the year used as an example in the present investigation. Ground-water pumpage is known to have increased from 90 mgd in 1954 to 110 mgd in 1964.

The trend of increasing water use is expected to continue. As the area's industrial capacity increases, so does the water demand. Increased industrialization is expected to bring about population increases, which will place added demands on the area's municipal water supplies, nearly all of which depend on ground water as the source. Per capita water demand probably will also continue to increase owing, at least in part, to expected increases in the use of automatic washing appliances. The most conservative estimate is that the 1964 rate of water use is likely to be doubled by the year 2000. According to some estimates, water use will double by 1980. The truth probably lies somewhere between these two extremes. In any event, the gravel aquifers of the lower Great Miami River valley will undoubtedly be required to meet greatly increased water demands in the future.

If water is withdrawn from an aquifer at a rate that exceeds the rate of recharge over a period of years, overdraft of the system results, as indicated by per-

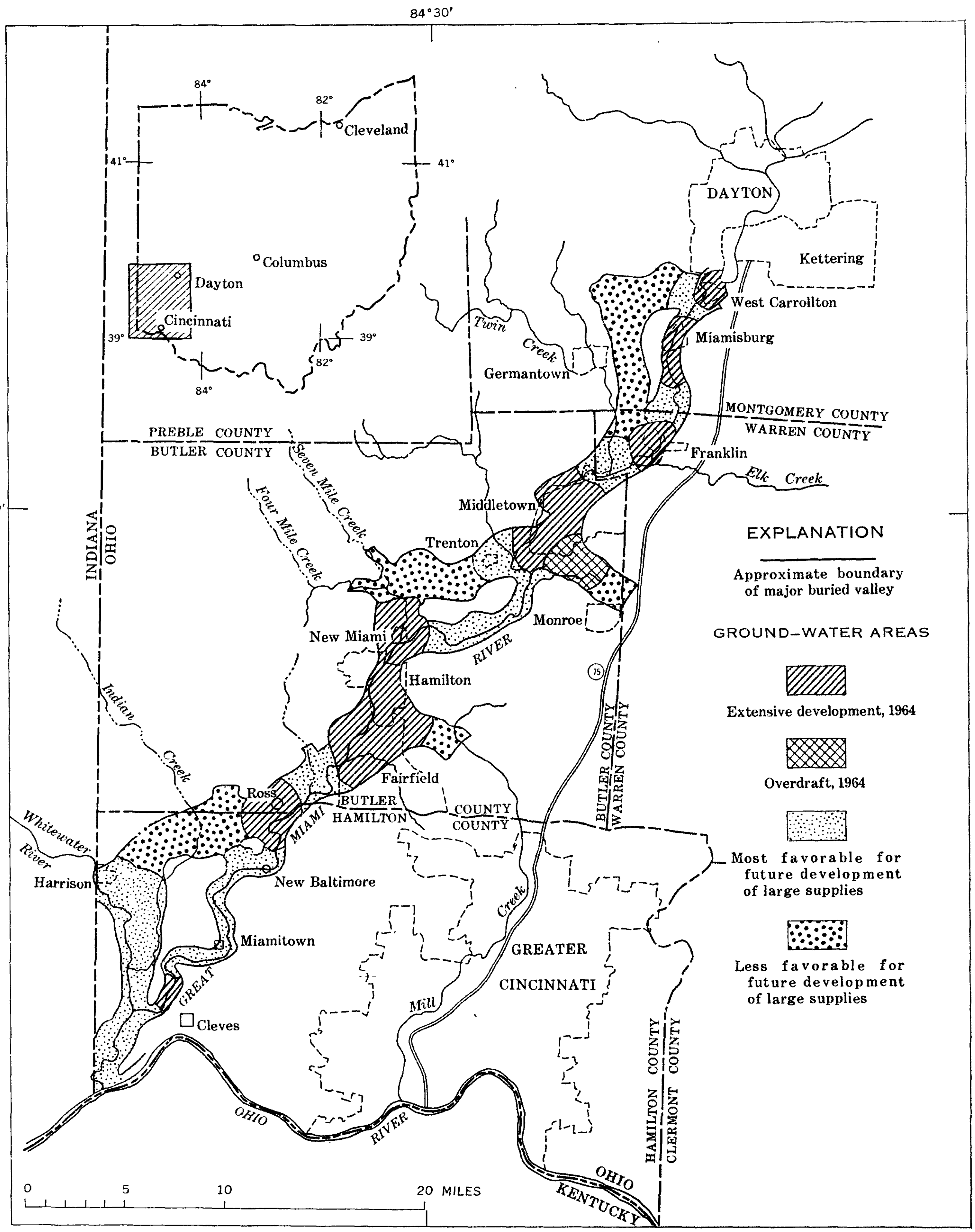

FIGURE 1.—Areas of present and future development of large supplies of ground water.

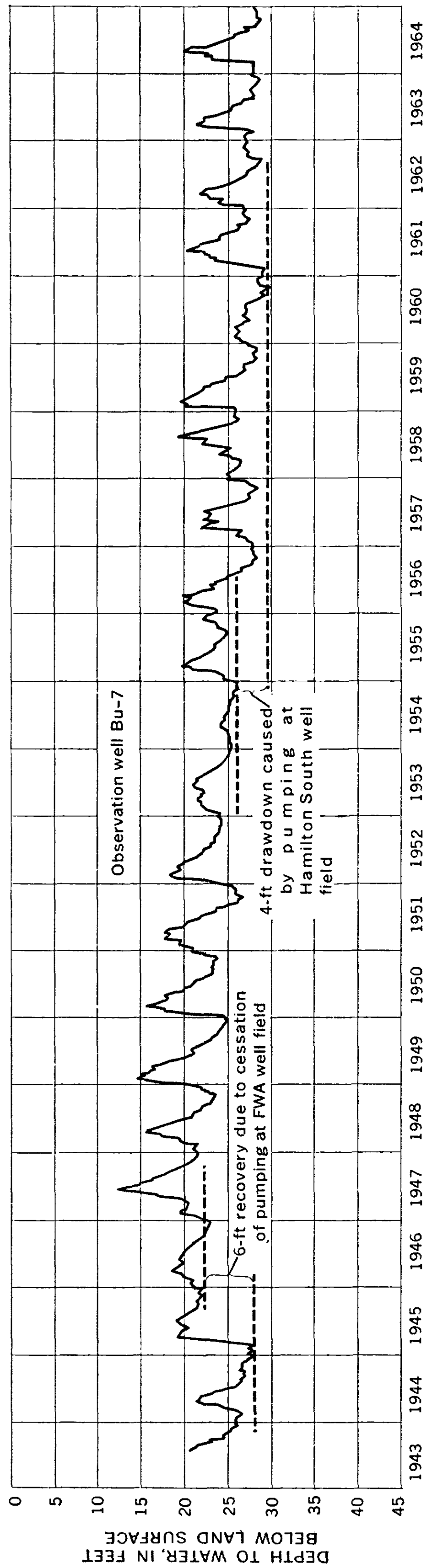

FIGURE 2.—Effects of recharge and pumping on water levels in the Hamilton South well field.

sistently declining water levels. In 1964 this situation exists in only one part of the lower Great Miami River valley, near the Armco East Works, southeast of Middletown. Figure 3 is the hydrograph of observation well Bu–3 at this plant. Average daily pumpage of ground water for each year of record is shown below the graph. The hydrograph indicates alternating periods of overdraft and recharge, varying largely with the rate of pumping at the plant. During this period of record, ground-water levels generally remained stable or rose when the pumping rate was less than 8.5 mgd, and they generally declined when pumpage exceeded this amount. The foregoing statement is simply an empirical observation, as other factors can significantly affect rates of recharge, such as variations in precipitation and evapotranspiration rates. The record of ground-water levels indicates that the perennial yield, or "safe" yield, of the aquifer in this vicinity is about 8.5 mgd. Thus, the water supply of the plant is very limited.

Two alternatives are available to any industry that has a water-supply problem. The industry can either make more efficient use of its available supply or seek additional sources of supply. For example, Armco could pipe water from additional wells developed on company-owned land near Trenton or it could make more efficient use of the available supply. The procedures for water reuse adopted by Armco are an example of how more efficient use can be made of an existing resource.

ECONOMY AND EFFICIENCY IN WATER USE

Water is generally abundant in the Great Miami River valley. As a result, the area's economy, which is largely industrial, is keyed to this abundance. Most industries in the lower Great Miami River valley have taken water for granted and have not seriously attempted to conserve water, as industries in areas where water is scarce have been forced to do. Up to now, the present report series has considered problems of supply and has not considered what is done with the water once it is taken from the ground. Economical utilization of water, however, can have a pronounced effect on supply if processes can be developed whereby industrial capacity can be maintained while water consumption is reduced. How one plant effected such economies can be seen in the pumping history of the Armco East Works.

The East Works of Armco Steel Corp. at Middletown is the largest industry in that city and one of the largest in the mapped area. As a producer of rolled steel products, this factory requires a large amount of water, mostly for cooling purposes. The plant is located on the east side of the buried valley of the ancestral Great Miami River at the mouth of the buried valley of ancestral Todds Fork, in the southeastern part of Middletown. The sand-and-gravel aquifer in this buried valley is less than 100 feet thick and is covered by a layer 100 feet or more thick of till and lake clay that acts as a semiconfining bed. Much of the sand and gravel is fine grained and of low permeability. The Great Miami River, about a mile and a half distant, is the nearest adequate source of water either for recharge to the aquifer or for an alternate supply. These factors combine to limit the development of a large water supply in the immediate vicinity of the Armco East Works.

Because of the plant's location, the ground-water supply in the vicinity has been taxed to the utmost. From 1939 to 1955 Armco pumped between 7.2 and 10.5 mgd of ground water and required, in addition, as much as 19 mgd of surface water. The hydrograph of observation well Bu–3 (fig. 3) at the plant shows gradual depletion of the aquifer. From a depth of about 100 feet when the record was begun in 1939, the water level in this well declined steadily (broken only by partial recovery in years of abundant rainfall and relatively low pumping) to 145 feet in 1955. Clearly, pumping at the then prevailing rate could not be continued indefinitely. The company had three possible ways of solving their water-shortage problem: cutting production, seeking alternate sources of water, or using less water. The last course of action was chosen.

In 1955 Armco initiated a program of improving its utilization of water. A clarifier capable of treating and recycling 23 mgd of water and five cooling towers capable of recirculating about 40 mgd were put into operation. As a result of these procedures the plant was able to double its production while reducing its use of ground water to around 8 mgd and its use of surface water to around 10 mgd. The plant's total water demand is over 80 mgd, of which less than 20 mgd is actually replenished from ground- and surface-water sources. The remainder is recycled. The recovery of the water level in Bu–3 in 1956, though partially due to abundant rainfall, reflects the effect of this reduction of pumpage.

After the water conservation measures were put into effect, however, increased plant production again forced ground-water pumpage beyond the critical level of 8.5 mgd. From 1959 through 1964 (fig. 3), pumpage averaged 9.7 mgd. Pumping at this rate, together with the generally dry conditions that prevailed during this period, caused the water level to decline steadily, from a high of 78 feet below the surface in 1959 to a low of 132 feet by the end of 1964. Unless abundant recharge in the near future reverses the trend, the plant will again be forced to reevaluate its water utilization.

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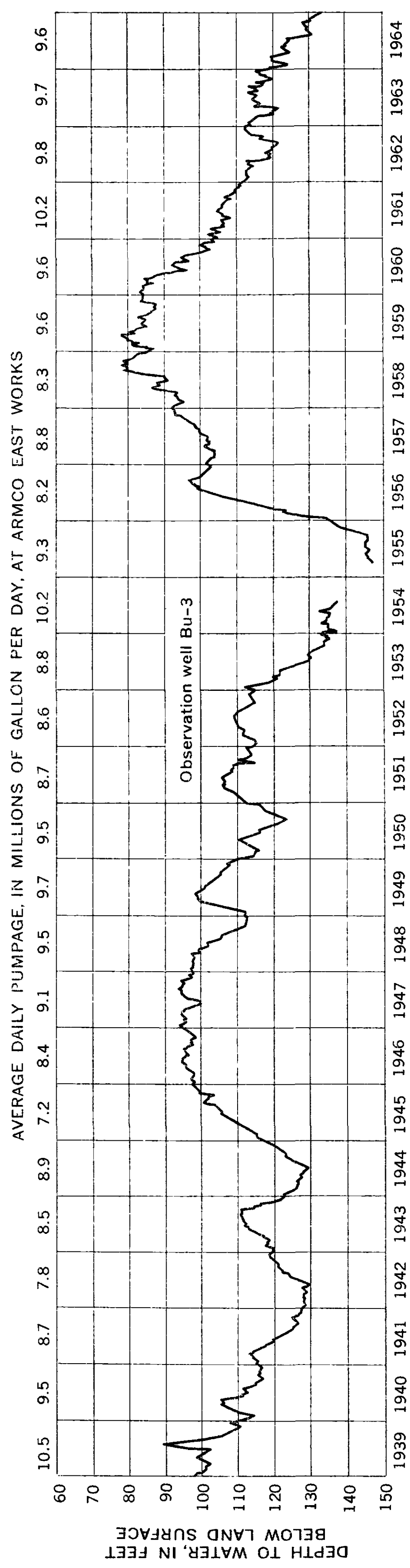

FIGURE 3.—Alternating effects of recharge and pumping overdraft on water levels at the Armco East Works, southeast of Middletown.

In 1965 Armco began expanding its facilities with a new plant, about a mile southeast of the existing East Works. Test drilling at the plant site indicates that an abundant ground-water supply is available. The static water level in test wells ranged from 14 to 35 feet below the surface. The water surface is relatively high at present, but because the new plant is situated in the same hydrogeologic environment of limited supply as is the present East Works, the cone of depression caused by pumping at the new plant may eventually intersect the cone around the existing production wells and result in further spreading of the overall cone of depression in the area. Water levels in this vicinity should be monitored so that corrective measures can be taken if the aquifer should appear to be in danger of being dewatered at some future date.

The foregoing example of efficient water utilization is cited to suggest one possible solution to the problems of increased water use. When similar situations arise elsewhere in the Miami River valley, more efficient utilization of water should be considered as an alternative to developing additional supplies. The abundance of water in the Great Miami River valley implies that little effort has had to be made to conserve it. Water-conservation measures such as those effected by Armco may involve considerable expense and are not likely to be undertaken unless there is no less costly method. In the future there may indeed be no less costly alternative. When problems of overdraft or declining water levels arise, the amount of water pumped usually is reduced, which may involve curtailment of plant operations. It would be well in the future to design plant facilities that require a minimum of makeup water in recirculation systems.

The overdraft problem at the Armco East Works is an exceptional situation in the lower Great Miami River valley. At the present rate of increase in the area's water requirements, overdraft of this magnitude probably will not become widespread in the foreseeable future, unless major well fields are developed near or within the present pumping centers.

POTENTIAL FOR FUTURE GROUND-WATER DEVELOPMENT

The potential sustained yield of the lower Great Miami River valley's aquifers exceeds present use. Figure 1 shows that less than half the total area of these aquifers has been developed. Even the areas shown in figure 1 as developed have not necessarily been tapped to their maximum potential. The area's present pumpage of 110 mgd is largely concentrated around the major cities; vast segments of the aquifer remain virtually untapped.

The term "sustained yield" as used in the following discussion refers to the initial withdrawal which can be achieved without exceeding the rate of recharge to the aquifers over an extended period of time. As discussed in chapter A of the present series (Spieker, 1968a), the pumping of ground water from an aquifer hydraulically connected with a stream will, on the average, reduce the flow of the stream between the point of withdrawal and the point of sewage return. However, since most of the water withdrawn from the aquifers is returned to the Great Miami River as sewage at a point near the point of withdrawal, the net effect on streamflow is slight. Thus, some of the streamflow consists of used water; through induced recharge, some of this used water is recycled back into the aquifers. As both the withdrawal of ground water and the discharge of sewage into the stream are expected to increase in the future, it is possible to visualize repeated recycling of water from the ground to its point of use, to the river, and then back into the aquifers. The system's sustained yield can thus be exceeded without depleting the aquifer.

An indication of the sustained yield of the area's aquifers can be obtained by projection of the results of an analog-model study of the Fairfield-New Baltimore area, southwest of Hamilton. This study, a part of the present investigation, was undertaken to determine the hydrologic effects of a large ground-water supply being considered by the city of Cincinnati. The results of the study are described in detail in chapter C (Spieker, 1968b). The following brief summary is intended to show that the hydrologic system in this part of the project area is capable of sustaining nearly four times the present rate of initial withdrawal.

The Fairfield-New Baltimore area is underlain almost entirely by the 32-square-mile segment of the valley-train aquifer immediately southwest of Hamilton (fig. 1). Figure 4 is a map showing the drawdown caused by pumping in this area through the end of 1962. Total pumpage in the area averages 22 mgd, concentrated mainly at two centers: the Southwestern Ohio Water Co. well field in the western part of the area, pumping about 13 mgd, and the Hamilton South well field in the eastern part of the area, pumping 7.5 mgd (fig. 4). The maximum drawdown is 15 feet, at the Southwestern Ohio field. As the saturated thickness of the aquifer is more than 150 feet in most of the area, this drawdown is not considered to be excessive. Analysis of analog-model data indicates that the cone of depression had ceased spreading long before 1962, the end of the modeled pumping period.

Figure 5 is a drawdown contour map of the same area showing the predicted effect of pumping of 40 mgd (in addition to all present pumping) at the site

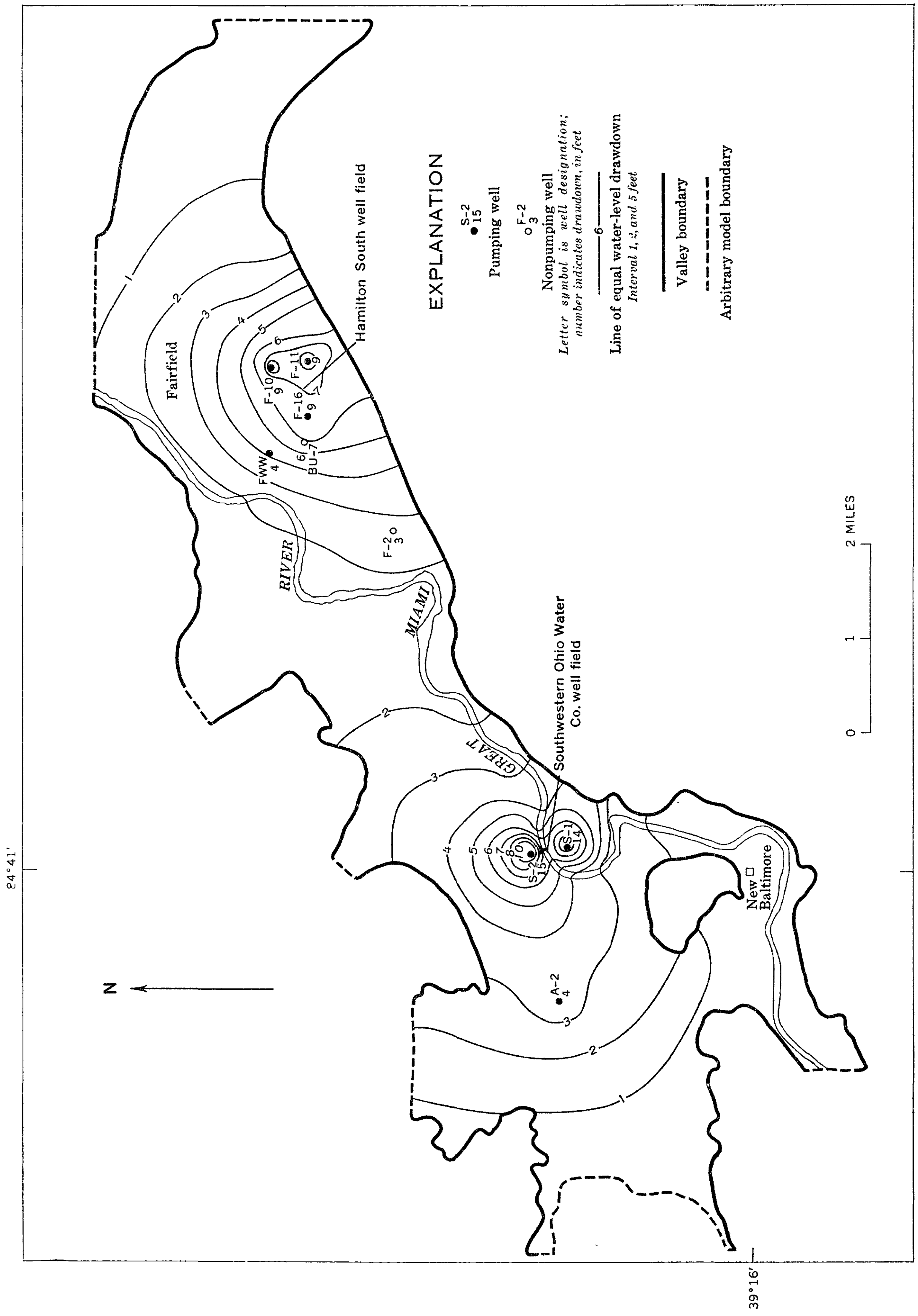

FIGURE 4.—Map of the Fairfield-New Baltimore area showing drawdown caused by pumping, 1952-62. Data based on analog study.

proposed by Cincinnati for the period 1962–82. Pumping at existing well fields is doubled for the period 1972–82, simulating the anticipated increase in future water demands. The total pumpage in this simulated run is 84 mgd—nearly four times the present rate. The cone of depression caused by this anticipated pumping increase extends beneath the entire area. The maximum drawdown is 32 feet, at the Southwestern Ohio and the proposed Cincinnati well fields. As in the previous example, model studies (Spieker, 968b, fig. 23) indicated that equilibrium will have been attained long before the end of the pumping period. Under these modeled conditions the aquifer system of the Fairfield-New Baltimore area can sustain indefinitely pumping of 84 mgd without any further spreading of the cone of depression.

The analog-model study of the Fairfield-New Baltimore area can be used as a basis to estimate the sustained yield of the valley-fill aquifers of the entire lower Great Miami River valley. This study shows that the Fairfield-New Baltimore area can yield 62 mgd more than the present initial withdrawal rate of 22 mgd, a total initial withdrawal of 84 mgd. The parts of the report area shown in figure 1 as favorable for ground-water development total about 1½ times the size of the Fairfield-New Baltimore area.

Owing to the similarity of the hydrogeologic environment of these favorable areas—the valley-fill aquifers—to that of the Fairfield-New Baltimore area, the analog-model study can be projected to estimate the sustained yield of the favorable areas to be 126 mgd, or 1½ times that of the Fairfield-New Baltimore area. The present pumpage of 110 mgd in the lower Great Miami River valley, added to the preceding 126 mgd for the favorable areas and the additional 62 mgd for the Fairfield-New Baltimore area total 298 mgd, which can be regarded as a conservative estimate of the sustained yield of the lower Great Miami River valley aquifers. The estimate is conservative for three reasons. First, 84 mgd is less than the maximum possible sustained yield of the Fairfield-New Baltimore area. Second, the estimate does not include any further development that might be possible in the areas already tapped by pumping wells. These areas are by no means fully developed. Chronic overdraft is likely to result only if additional large ground-water supplies are clustered near existing centers of pumping or if present pumping rates are substantially increased. These centers are defined in greater detail in chapter A (Spieker, 1968a), pls. 1, 2). Finally, the foregoing estimate does not include development of the less favorable areas, which might yield as much as 20 mgd. Therefore, the sustained yield of the report area is, in round figures, at least 300 mgd, which is close to the discharge of 316 mgd, or 490 cubic feet per second, of Great Miami River at Hamilton that is equaled or exceeded 90 percent of the time.

The initial-withdrawal sustained yield estimated in the preceding discussion is meaningful only as a minimum amount of water which can be withdrawn from the valley-fill aquifers without exceeding recharge. Most large ground-water supplies, both existing and proposed, will be sustained by induced stream recharge. Availability of such recharge depends in large part on maintaining adequate streamflow. The withdrawal of ground water, as explained previously, will not cause any substantial net reduction of streamflow, because most of the water withdrawn from the aquifer is returned to the river as sewage.

Pumping at well fields from which water is transferred out of the Great Miami River drainage basin, such as the well field now operated by the Southwestern Ohio Water Co. and the one proposed by the city of Cincinnati, would result in a net reduction of streamflow. Southwestern Ohio Water Co. at present pumps about 15 mgd, and Cincinnati proposes to pump not more than 40 mgd. Even if Southwestern Ohio should double its present pumping rate, the total withdrawn from the drainage basin would be 70 mgd, which is less than one-quarter of the discharge of Great Miami River at Hamilton that is equaled or exceeded 90 percent of the time. Therefore, the interbasin transfer of 70 mgd would not result in any serious depletion of streamflow.

As long as the rate of interbasin transfer does not increase to the point where it becomes a major part of the river's base flow, the aquifer could be developed well beyond its initial-withdrawal sustained yield by recycling the water from the aquifer to the point of use, to the river as sewage, and then back to the aquifer as induced recharge. If quantity were the only factor involved, there is no reason why this cycle could not be repeated indefinitely.

Constraints are certain to be imposed on the use of the aquifer system beyond its initial withdrawal sustained yield, however, by considerations of water quality and economics. The water returned to the river is generally of poorer quality than that initially withdrawn from the aquifers. Such deterioration of quality may result from both the addition of wastes and an increase of the water temperature. Increased pumping, accompanied by increased discharge of sewage into the river, is therefore likely to result in ground-water contamination through the infiltration of contaminated used water. For this reason, any increase in the withdrawal rate substantially beyond the sustained yield of 300 mgd would have to be accompanied with either

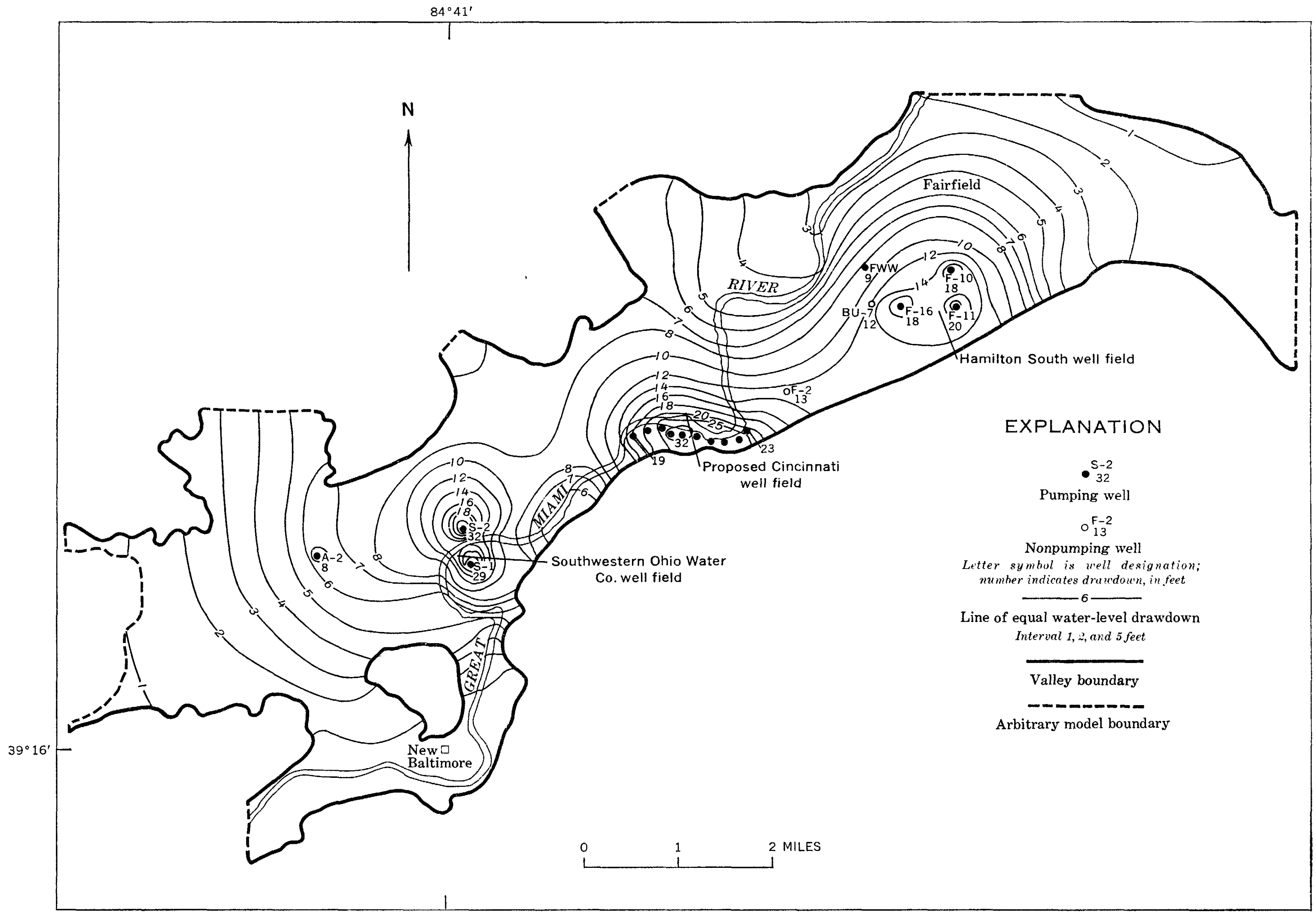

Figure 5.—Probable drawdown in the Fairfield-New Baltimore area caused by anticipated pumping, 1962–82. Data based on analog study. For 1972–82, pumping at proposed Cincinnati well field assumed to be 40 mgd, and at existing well fields, 44 mgd.

a higher degree of sewage treatment or an augmentation of the river's low flow.

Although measures to improve the quality of river water with increased ground-water use may prove to be technologically feasible, the cost may be prohibitive. On the other hand, improvements in technology might also reduce the cost of treating wastes. In the final analysis, the ultimate limit on the use of the ground-water resource in the lower Great Miami River valley may be dictated by economic considerations rather than by technology or the capacity of the aquifer system.

The ultimate extent of development of the area's ground-water resource will have to be based on consideration of the close interconnection of the ground-water and surface-water components of the hydrologic system. Any well-integrated and well-coordinated plans for development of the area's water resources must balance water supply needs with needs for waste dilution, recreation, and the esthetic objective of maintaining clean and attractive streams.

Two techniques which may be used to accomplish these other objectives in conjunction with the effective development of the ground-water resource are flow augmentation and artificial recharge.

FLOW AUGMENTATION AND ARTIFICIAL RECHARGE

Most large ground-water supplies in the lower Great Miami River valley are at the present time sustained by induced recharge from the river. It is estimated that such induced recharge could sustain three times the present rate of initial withdrawal provided future ground-water developments are properly spaced and located favorably with respect to the stream. Development of supplies with yields in excess of this quantity, however, may require such measures as artificial recharge. At the present time, artificial recharge is not practiced in the lower Great Miami River valley, mainly because it has not yet been necessary. The city of Dayton, however, has depended on artificial recharge for many years to sustain the major part of its municipal water supply of over 40 mgd. Water from the Mad River is diverted into a series of interconnected lagoons from which it is allowed to infiltrate the sand and gravel aquifer. This system was described by Norris and Spieker (1966, p. 83–88). Thus, the city of Dayton can pump as much as 60 mgd from its Rohrers Island well field while maintaining water levels generally less than 30 feet below land surface.

Artificial recharge as a means of increasing aquifer yields in the lower Great Miami River valley might be used in connection with any of the various proposals for augmentation of the low flow of the Great Miami River. Low-flow augmentation, whereby peak runoff is stored in reservoirs and gradually released during extended periods of low flow, is intended primarily to improve the chemical quality of the river water during these periods by diluting contaminants. Maintaining a high flow of water of reasonably good quality would increase the amount available for artificial recharge during dry-weather periods. Such measures might best be used as part of an overall program of basin-wide water management.

CONTAMINATION

One of the principal advantages of a ground-water supply over a surface-water source in the lower Great Miami River valley is that the chemical quality of the ground water is superior in some important aspects. The Great Miami River, like most streams in heavily populated and industrialized areas, has been subjected to contamination by sewage and industrial wastes, particularly during periods of low flow. The dependence of many large ground-water supplies on recharge by induced stream infiltration therefore raises the distinct possibility that these supplies might become contaminated.

The foregoing statement does not imply that induced recharge from polluted streams will invariably result in the serious contamination of ground-water supplies. The relation between pollutants in surface waters and the ground-water environment is a complex one. Some contaminants may be eliminated or reduced in concentration by filtration, sorption, dilution, or ion exchange while passing through the aquifer materials (Deutsch, 1965, p. 39). Other contaminants may not be so affected. Many of the bacteria present in polluted streams will be killed in the anaerobic environment of ground water. Generally, ground water receiving induced recharge from a polluted stream can be expected to be of better quality than the stream water. Much additional research is needed to fully understand the effects of induced infiltration on various pollutants present in streams.

Whereas contamination of a stream is a transient phenomenon and will disappear quickly once corrective measures are taken, contamination of a ground-water supply is far more persistent. Once contaminants get into an aquifer, it might take many years for the ground water to flush them out owing to its slow movement.

Water in some wells recharged by induced stream infiltration has become slightly contaminated—chiefly in wells in and near the major pumping centers of Chautauqua, Middletown, Hamilton, Fairfield, and Ross. Evidence of contamination consists of the presence of minute quantities of substances such as detergents (ABS), phenols, and ammonia nitrogen which do not occur naturally in waters. Although the degree of contamination is not yet sufficient to render the water unfit for consumption or even to be considered serious, the quality of water from wells known to be receiving induced recharge should be periodically checked so that corrective measures can be taken should the contamination appear to become serious.

As more and more ground-water supplies become dependent on recharge by induced stream infiltration, the problem of ground-water contamination can be expected to become more widespread. The only possible means of averting this problem is to go to the source of the contaminants and either prevent or regulate their dissemination. (This would involve preventing contaminants from entering the streams, or, alternatively, ensuring that the concentrations of contaminants are maintained at acceptable levels.) Flow augmentation appears to be one acceptable solution to the problem of contamination. Other solutions might be a more complete treatment of sewage and industrial wastes or an alternate means of disposal for the most highly toxic substances. In short, the only way to prevent contaminated stream water from entering the valley aquifer is to maintain an acceptable quality of water in the streams.

WATER-RIGHTS LAW

GROUND-WATER LAW IN OHIO

As the withdrawal of water from a hydrologic system approaches the capacity of that system, conflict is bound to develop among the various users of water. Resolution of such conflicts is achieved in courts of law. Thus, to examine the water laws of Ohio and to discuss their relation to both the problems of today and those anticipated in the future is pertinent to the present investigation.

Two basic types of water-rights law exist in the United States: the doctrine of riparian rights and the doctrine of appropriation. The doctrine of riparian rights, which dates to early English common law, is based on *ownership* of land and applies generally in the Eastern States, where the climate is humid. In general terms, the doctrine of riparian rights as modified by courts in the United States holds that the owner of land adjacent to a stream or lake is entitled to reasonable use, on the riparian land, of the water of said stream or lake and to underground water from any well or spring on his property. The owner retains his right to this water whether he uses it or not. Such a doctrine would not be adequate where the climate is arid, as in the western part of the United States, where the water supply is smaller than the demand. Consequently, the doctrine of appropriation has been adopted by many of the Western States. This doctrine is a statutory law which considers all water as public property and grants rights to citizens based on *use* of the water. A generalized statement of the doctrine of appropriation in its original form might be that the first user to be granted a water right by the State has precedence over subsequent users, and he must continue to use the water in order to maintain his right to its use. The doctrine has been modified in several States so that a user need not continually use the full amount of his appropriation in order to maintain his right. The preceding explanations are, of course, considerably simplified; the water-rights law of many States contains elements of both these doctrines.

Water-rights law in Ohio is based on the doctrine of riparian rights, as modified by various court decisions. Three decisions are particularly significant in the application of water rights to ground water in Ohio.

In the case of *Frazier* v. *Brown*, 12 O.S. 294 (1861), the plaintiff claimed that the defendant dug a hole on his own property but near a spring on plaintiff's property. The plaintiff contended that, in digging the hole and withdrawing water from it, the defendant had destroyed the plaintiff's spring and a stream which had been fed by the spring and had flowed over the plaintiff's property. The court, in disregarding the plaintiff's allegation, classified all waters into four categories: (1) surface streams which flow in permanent, distinct, and well-defined channels; (2) surface waters without any distinct channel; (3) subterranean streams; and (4) subsurface percolating waters. The court then decided that the case should be treated as involving only rights in percolating water, not recognizing that ground water and surface water are interrelated. In recognizing no rights of ownership of percolating waters, the court stated the following opinion (p. 311):

> Because the existence, origin, movement, and course of such waters, and the causes which govern and direct their movements are so secret, occult, and concealed, that an attempt to administer any set of legal rules in respect to them would be involved in hopeless uncertainty, and would be, therefore, practically impossible.

This decision reflected the general knowledge of the hydrologic cycle in 1861.

An Ohio court in 1887, however, rendered a decision which follows a line of reasoning opposite to that of the *Frazier* v. *Brown* case. The case of *Warder and Barnett* v. *City of Springfield*, 9 Ohio Dec. Rep. 855 (1887), arose when the City of Springfield excavated below the water table for its public water supply near Buck Creek in Clark County. Pumping of water from this hole reversed the natural hydraulic gradient and caused water to flow from the stream into the aquifer. The plaintiff contended that this pumping and the resultant reduction of streamflow reduced the flow through his millrace. The lower court granted an injunction against the defendent based on the following opinion:

> No man can rightfully dig a channel from a running stream, and thus divert the waters thereof to the injury of a lower proprietor. *What he cannot do directly, he cannot do indirectly.* He therefore has no right to construct a well, trench, or reservoir upon his own land, in such manner that by filtrating or creating artificial underground channels, he will withdraw water through the soil from a running stream to the injury of a lower proprietor.

Here, the court recognized that the stream and the aquifer are parts of the same hydrologic system and that taking water from the ground would, in effect, reduce the flow of the stream.

In a later case, a lower court reverted to the philosophy of the *Frazier* v. *Brown* case. The Miami Conservancy District in 1924 deepened the channel of the Mad River near Dayton, resulting in a lowering of the water table. A landowner adjacent to the river sought damages (*in re Miami Conservancy District*, 25 Ohio N.P. (ns.) 325 (1925)), claiming that said lowering of the water table put him to considerable expense in deepening his well. The court denied his claim, holding that the water in the aquifer was moving toward the stream, rather than away from it, and hence should be regarded as percolating water.

Contamination of ground-water supplies has not as yet become a generally serious problem in Ohio. Consequently, there is little legal precedent. The common law, as clarified in *Frazier* v. *Brown*, holds that "the considerations of policy which govern the right to take water do not apply to its pollution. Pollution of percolating water is a wrong for which an action will lie and * * * the liability does not depend on negligence" (Callahan, 1957, p. 22). In other words, the liability for pollution is absolute. Ohio Revised Code (1951), section 6111 states: "Under this law it is unlawful * * * to discharge harmful substances into *any of the waters* in the state except under a valid permit issued by the pollution control board." [Italics added by the author.]

These laws and legal precedent pertaining to pollution appear to be adequate to deal with any situation involving ground-water contamination; but contamination of ground water, unlike contamination of a stream, is not a transient phenomenon. Once a contaminant is in the ground, it may be several years, or even decades, after the contaminant is discovered and its source isolated before it is completely discharged from the aquifer. Although adequate legal control must be maintained the only real remedy for the contamination of ground water is its prevention.

So far in the history of Ohio, relatively few cases involving water rights have had to be settled in courts of law, owing chiefly to the general abundance of water and the lack of conflict over its use. In the future, however, as the demand for water increases while the supply remains constant, it is highly probable that an increasing number of water-rights cases will come to court. The doctrine of riparian rights as modified by judicial decisions has generally been adequate for dealing with problems involving water rights up to the present; however, in the future these laws may not prove adequate.

Legislation may be required in the future to eliminate any confusion and to set up well-defined standards for the solution of water-rights problems. To be effective, such legislation should be based on sound scientific principles.

CINCINNATI WELL FIELD CASE

In recent years a situation involving water rights in part of the lower Great Miami River valley has generated considerable interest. The city of Cincinnati announced plans in 1961 to develop a large ground-water supply near Fairfield, southwest of Hamilton. Details of the proposal and the hydrogeologic setting of the Fairfield-New Baltimore area are discussed in chapter C of the present series (Spieker, 1968b). Cincinnati, whose population exceeds that of the entire lower Great Miami River valley area, is not so fortunately situated with respect to ground-water supplies. Its present source, the Ohio River, is relatively distant from the rapidly expanding northwestern suburban area and is subject to pollution during periods of low streamflow. The perennial yield of the sand and gravel aquifer in the Mill Creek valley—Cincinnati's major industrial district—is only about 8.5 mgd.

On two previous occasions, Cincinnati industry has sought relief from water shortages by coming to the more plentiful sources in the Great Miami River valley. First, in World War II the Federal Works Agency developed a well field in the valley south-southwest of Hamilton to supply the Wright Aeronautical Corp. plant at Lockland. From July 1943 through August 1945 this well field yielded an average of about 8 mgd (Bernhagen and Schaefer, 1947, p. 20). After the war, pumping was discontinued, and the well field was sold to the city of Hamilton, which reactivated it in 1956 as the South well field.

In 1952 a group of 13 industries in the Mill Creek valley area formed the Southwestern Ohio Water Co., a cooperatively owned subsidiary whose sole purpose is to supply water to the plants. A well field was developed near Ross, from which water is pumped through a pipeline over the divide and into the Mill Creek valley to a reservoir near Sharonville. Pumpage at the well field averages about 13–15 mgd.

Cincinnati's present proposal, then, is the third time that interests in the Cincinnati metropolitan area have turned to the Great Miami River valley for ground water. The proposal has met with considerable opposition owing to the location of the well-field site in Butler County—the county adjacent to Hamilton County, in which Cincinnati is located (fig. 1). When the proposal was first announced, Butler County civic leaders expressed fears that the new well field might endanger existing water supplies. Although the results of several hydrologic investigations (Spieker, 1968b) suggest that the new well field can be developed without endangering existing supplies, the proposal still has opposition.

In 1963 the Butler Water Conservancy District (not affiliated with the Miami Conservancy District) was created (No. 80379, Butler County Common Pleas Court) for the stated purpose of conservation of the ground-water resources of Butler County. The Conservancy Act of Ohio, enacted in 1914, permits citizens of any area to organize a conservancy district for flood control or other water-management purposes. In December 1963 the Butler Water Conservancy District obtained a temporary injunction against the city of Cincinnati that halted construction of the new well field.

The legal point in question in this case is whether or not a conservancy district has the right to prevent or regulate the development of a ground-water supply. The Conservancy Act (Section 6101. 1–84, Ohio Revised Code) specifies that a district may regulate streamflow. Inasmuch as the proposed ground-water supply would be sustained partly by induced stream infiltration, streamflow could conceivably be affected. Thus, the law could possibly be interpreted to mean that a district can regulate streamflow indirectly by controlling ground-water pumpage.

On December 27, 1963, Cincinnati filed a petition *in quo warranto* in the Ohio Supreme Court, challenging the right of the Butler Water Conservancy District to prevent construction of the well field. In a unanimous decision on February 2, 1966, the Supreme Court (No. 38578, *State, ex rel. City of Cincinnati* v. *Butler Water Conservancy District*, 5 Ohio St. 2d) dismissed Cincinnati's petition, maintaining that Cincinnati does not have authority to invoke the original jurisdiction of the Supreme Court, thereby bypassing the Court of Common Pleas and the Court of Appeals. This decision, in effect, has settled only a point of law and has thrown the question of Cincinnati's right to develop its well field back to the Butler County Common Pleas Court.

Another legal question pertinent to the Cincinnati case, though not an issue in the current litigation, concerns the matter of interbasin transfer of water. Although such transfer is a common practice in Ohio, as well as elsewhere, to the author's knowledge it has never been challenged in Ohio courts. There exists, however, a precedent in the case of *Forbell* v. *City of New York* (1900 164 N.Y. 522, 58 N.E. 644), in which the court ruled that the use of ground water must be reasonable, and that the use on land not overlying the water source was not reasonable. This decision, though it has been followed in other States, predates modern concepts of water management, which recognize and even advocate interbasin transfer as a desirable management practice.

SUMMARY AND CONCLUSIONS

Increased use of ground water appears certain in the future development of the lower Great Miami River valley. If future ground-water supplies are located where they can be sustained by induced stream infiltration and away from existing centers of pumping, the area can probably sustain an initial withdrawal rate of 300 mgd, or nearly three times the present pumping rate of 110 mgd. The rate of 300 mgd should not, however, be considered as a limit on the development of the area's ground-water resource. Unless a substantial part of the initial withdrawal is removed from the Great Miami River basin, most of the ground water initially withdrawn will be eventually returned to the river as sewage. Therefore, increased ground-water pumpage will result in little depletion of streamflow, as the water will be, in effect, recycled from the aquifers, through the point of use, back to the river as sewage, and finally, back to the aquifers as induced recharge. The only limits on the number of times the water can be recycled are imposed by the deterioration of water quality with each reuse and the cost of more complete treatment than is presently accomplished. Artificial recharge of the aquifers and augmentation of low flow in the river can enhance both the efficient development of the ground-water resource and the maintenance of adequate quality of the river water. Much more research into the interrelation of surface water and ground water as components of the hydrologic system will be needed to ensure the optimum development of the area's ground-water resource.

The two most serious problems likely to be encountered relate to declining ground-water levels and local overdraft caused by increased water use and to ground-water contamination. The problem of overdraft can be partially averted by giving careful consideration to the location of large ground-water supplies where the aquifer is not yet extensively developed. Good examples of such places are the segments of the Great Miami River valley between Franklin and Middletown, the vicinity of Trenton, the area between Fairfield and Ross (where Cincinnati proposes to build its well field), and in the lower Whitewater River valley south of Harrison. This last part of the area is the largest untapped source of ground water in southwestern Ohio.

Overdraft of the ground-water supply can also be curtailed by economical use of water by industry. If the demand for water at any locality approaches and threatens to exceed the supply, industries should consider management of use (including reuse of water) as an alternative to developing new supplies.

Ground-water contamination is not yet a serious problem in the lower Great Miami River valley. Since nearly all contaminants in the aquifer are derived from induced stream recharge, the obvious way to eliminate ground-water contamination is to clean up the river. Low-flow augmentation is being considered for this purpose. Ground-water supplies receiving recharge by induced stream infiltration should be checked periodically so that corrective measures can be taken before contamination becomes serious.

The problem of water-rights law has not yet affected the area as a whole, although Cincinnati's proposal to construct a new well field has created some controversy. Should legislation become necessary to resolve problems involving water rights, a thorough understanding of the hydrologic principles would be helpful in governing the situation.

The lower Great Miami River valley is favored with an abundance of ground water. If this valuable resource is wisely managed, it should be sufficient for the requirements of several generations yet to come. Plans for management of the ground-water resource, however, must include careful consideration of all components of the hydrologic system and, in particular, the effects on the surface-water regimen caused by increased pumping of ground water.

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