

# GROUNDWATER RESOURCES

A PRIMER

for the Compact District  
of the Ohio River Basin



ILLINOIS  
INDIANA  
KENTUCKY  
NEW YORK  
OHIO  
PENNSYLVANIA  
VIRGINIA  
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A PRIMER ON  
GROUNDWATER RESOURCES  
IN THE COMPACT DISTRICT OF THE  
OHIO RIVER BASIN



SEPTEMBER, 1984

OHIO RIVER VALLEY WATER SANITATION COMMISSION  
414 WALNUT STREET  
CINCINNATI, OH 45202

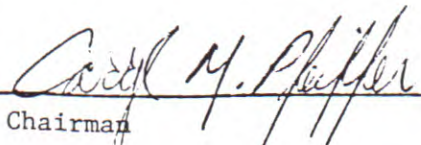


## FOREWORD

In 1983, the Ohio River Valley Water Sanitation Commission established an Energy Roundtable to provide a forum for discussion of policy issues and problems concerned with energy management and water pollution control, and related environmental-economic issues that have regional or multistate effects. The goal is to facilitate early and open communications through periodic meetings between the energy industry and related interests and the signatory states. The Energy Roundtable serves as a public forum for any and all energy matters of interest to the Ohio Valley public interests. Groundwater resources was the initial topic selected for discussion by the Energy Roundtable. Information and research in this report was compiled as a source document dedicated to various issues related to groundwater resources.

Special acknowledgment is due Mr. William L. Klein, Assistant Executive Director and Randy D. Meyer, Graduate Intern, who researched the literature, prepared the map of major aquifers in the Compact District, and drafted the initial report. Russell Brant, Geologist with the Kentucky Geological Survey, reviewed the hydrogeological sections.

Membership on the Energy Roundtable consists of one Commissioner from each of the signatory states; one Commissioner from the federal government; a member of the Public Interest Advisory Committee; and one member each from the Power Industry Committee and East Central Area Reliability Council (ECAR).

  
Chairman

Members of the Energy Roundtable are:

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Illinois Environmental Protection Agency

Indiana: Albert R. Kendrick, Jr.  
Safety & Environmental Protection  
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## Executive Summary

The survey is a compilation of data and information obtained from state, federal and local agencies concerning the groundwater resources in the Compact area of the Ohio River Valley Water Sanitation Commission (ORSANCO). A map accompanies the report which shows the major aquifers and potential groundwater yields. The predominance of high yield aquifers is located north of the Ohio River and along its main channel. The only high yield areas south of the Ohio River are in the Jackson Purchase Region of Southwestern Kentucky, which extends into extreme Southern Illinois; and in an area of Southeastern Kentucky that extends through West Virginia into Western Pennsylvania. The map should prove useful for site planning and regional development and in identifying areas that should be protected from groundwater contamination.

The Ohio Valley aquifer which follows the main channel of the Ohio River and borders on six states is the largest and has an estimated 4,500 billion gallons of groundwater available in storage. About 70% of this amount is located in the lower third of the river.

The availability of groundwater for the entire Compact area is estimated to be 17,700 million gallons per day (mgd). Of this amount, only about 2,500 mgd or 14% of the available groundwater is being withdrawn for use, exclusive of saline groundwater. Industry is the largest user withdrawing 1,300 mgd, or 50% of the total withdrawal, with facilities in the Monongahela, Upper Ohio River, Wabash and Lower Ohio River having the greatest usage. In the Wabash Basin, agriculture is the largest user of groundwater.

The region has extensive areas of connate or brine water located in aquifers below the active groundwater circulation that are being used by the chemical industry as a source of raw materials in the manufacture of chemicals. Brine water is also encountered in oil and gas production, and the disposal of the wastewater to prevent entrance into groundwater and surface water is a continuing problem.

Data on groundwater quality is limited to mineral analyses and a limited number of parameters such as pH and dissolved solids. Little data was found on the organic content of the major groundwater aquifers, except in instances connected with a disposal site for hazardous wastes. Considering the importance of such

data and the toxicity of many organic compounds, there is a need to increase the level of surveillance.

An increasing number of cases of groundwater contamination is being reported, such as the two cases cited in the report. Because many of the major aquifers transcend state lines, failure to protect groundwater resources has far-reaching implications. Seventy percent of the surface impoundments -- farm ponds, reservoirs, ash settling ponds, etc. -- nationwide overlie very permeable aquifers. Ninety percent of these impoundments are located within one mile of a drinking water source. Little or no information was found on the extent of groundwater pollution that may transcend state borders involving organic chemicals in the principal aquifers of the Compact area.





## INTRODUCTION

The Ohio River Valley is blessed with an abundance of water. The USGS (1984) estimates that about 7% of all freshwater withdrawn in 1980, excluding hydroelectric power generation, was groundwater, constituting a significant part of the total water resource. A simple water budget reveals that once evapotranspiration and groundwater recharge demands are satisfied, the precipitation excess is considered runoff to the stream. Having reached the saturated subsurface or phreatic zone, groundwater generally moves from areas of high head (i.e., high elevation) to low head (i.e., low elevation), primarily under the influence of gravity (Figure 1). During dry weather, when there is little or no surface runoff, groundwater is responsible for the flow of perennial streams and springs. This is known as base flow and contributes to surface flow at a relatively constant rate all year. As the hydrologic cycle shows (Figure 2) discharged groundwater becomes surface water, (after some delay), evaporates to the atmosphere, and eventually returns via precipitation.

# GROUNDWATER MOVEMENT FROM AREAS OF HIGH HEAD TO LOW HEAD

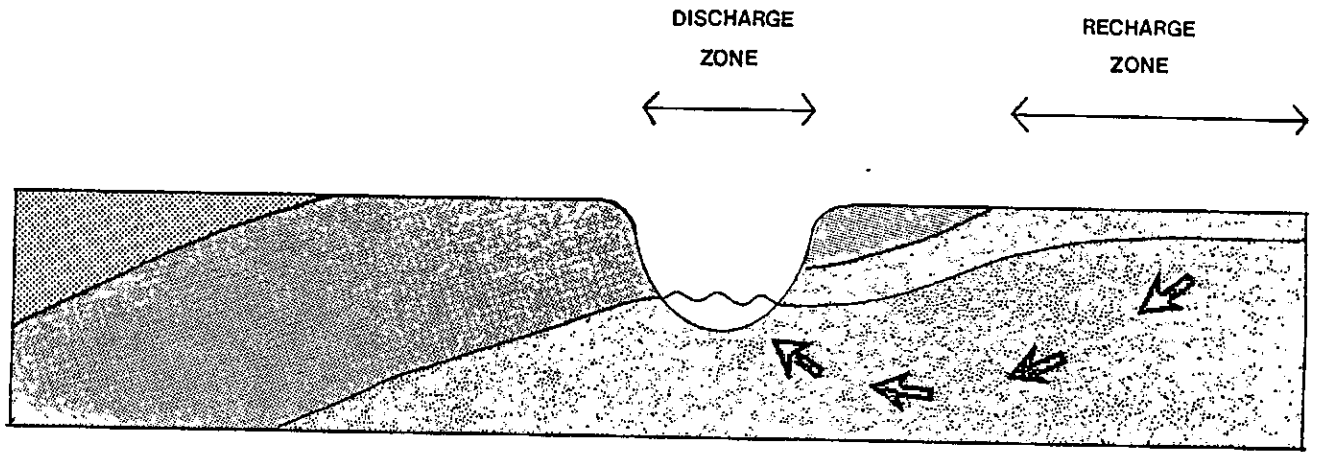
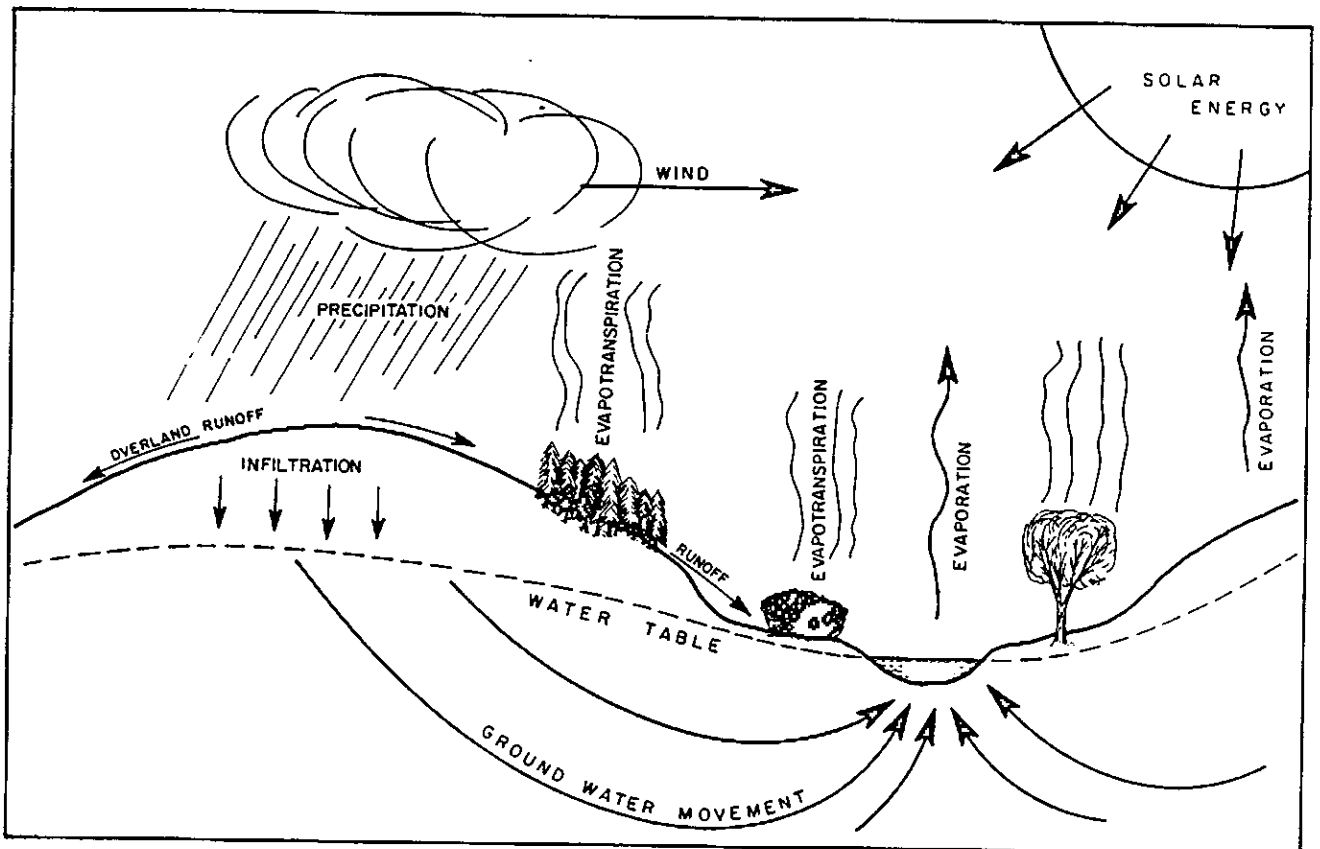


FIGURE 1

# THE HYDROLOGIC CYCLE



(From: Bain and Friel, 1972)

FIGURE 2

Misconceptions about the nature of groundwater continue to exist. This apparent lack of understanding stems from the fact that groundwater is not directly observable. It is commonly assumed that surface flow conditions also prevail in the subsurface. In reality, water-yielding geologic units more closely resemble a sponge: able to absorb and transmit water in circuitous pathways of interconnected pores -- not veins or rivers (Figure 3).

#### FLOW THROUGH POROUS MEDIA

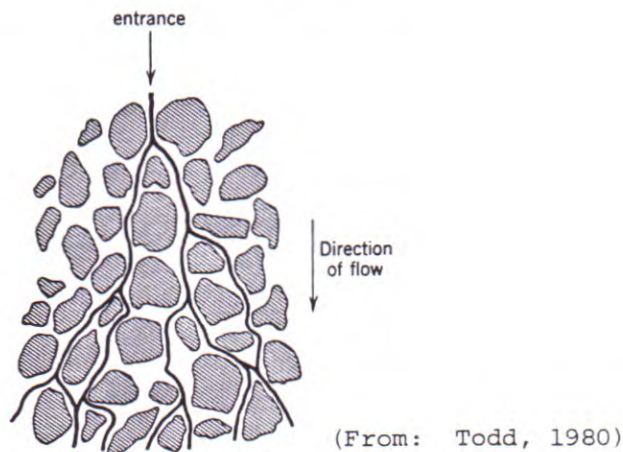


FIGURE 3

Rocks, especially those near the surface, are solid matter, but contain voids (porosity) or pore space and may be interrupted by joints or faults. Some or all of the rock's porosity (defined as the percentage of open space by volume) is due to the mechanics of formation, and is termed primary

porosity. Porosity which is generated subsequent to rock formation due to various chemical and mechanical processes (e.g., stress relief, faulting, and weathering) is secondary porosity.

Profuse space is not enough to sustain a large groundwater resource. There must also be pore interconnection or permeability. The ability of water to move through rock is known as hydraulic conductivity, and varies widely among materials. It is highly dependent upon pore size, shape, and arrangement. Consequently, permeable rock units generally perform like pipelines filled with sand in their ability to conduct water under a head differential. In fact, Henry Darcy used an analogous physical model in 1856 to develop the groundwater movement equation about which all scientific study of groundwater revolves. Darcy's law states that  $Q=KAI$  where:

$Q$  is the quantity of water per unit time (gallons per minute);

$K$  is the hydraulic conductivity (gallons per minute/sq. ft.);

$A$  is the cross-sectional area normal to the direction of flow (sq. ft.); and

$I$  is the hydraulic gradient or change in head per unit distance (dimensionless).



Because hydraulic conductivity (K) and cross-sectional area (A) are approximately constant, the quantity of water (Q) is directly proportional to the hydraulic gradient (I). This suggests that fluid flow is laminar (i.e., streamlined) or nearly so. Most geological conditions are conducive to laminar flow. When flow becomes turbulent, such as occurs in Karst regions (e.g., caves) and other large rock openings, the equation is no longer valid.

Porous rock, with high permeability, and a copious supply of recharge will result in a large, renewable supply of groundwater that may be tapped naturally by springs and streams or by wells. Groundwater is ubiquitous in the Ohio River Valley. Digging or drilling will produce groundwater anywhere, although not necessarily in a usable quantity. If groundwater is available, then the water-bearing layer (formation) is defined as an aquifer. It may or may not be in usable quantity or quality. For example, an aquifer or water-bearing unit capable of yielding several hundred gallons per day (GPD) would be an aquifer suitable for domestic water supply purposes, but would not be adequate for an industry requiring this volume per minute.

Commonly, aquifers are classified by their potential yield in gallons per minute (GPM) on a sustained basis. For the Ohio River Valley, the principal aquifers have been defined as those capable of yielding 100 GPM or more to many individual wells. Although 100 GPM is an arbitrary value depending upon, among other things, well construction and pump size, it represents the production level necessary to constitute a water supply for most large industry and medium to large municipalities. It is aquifers such as these that were deemed to be regionally significant, and have been chosen for detailed study because of their potential yield and other quality characteristics.

## PRINCIPAL AQUIFERS

There are two broad types of principal aquifers in the Ohio River Valley: the unconsolidated sands and gravels of glacial and coastal plain deposits and consolidated sedimentary rocks or bedrock. Plate 1 shows potential groundwater yields in the Compact District. The dark blue represents areas capable of yielding 100 GPM or more per well. The light blue represents areas capable of yielding more than 20 GPM but less than 100 GPM. The white represents areas capable of yielding less than 20 GPM. It should be noted that groundwater may occur in more than one geologic unit. Therefore, the indicated yield may be available from more than one aquifer. This is especially true north of the Ohio River where high yield glacial outwash overlies high yield bedrock in many places. Note that the shape of glacial and other aquifers that are not extensive may be completely masked by more extensive aquifers in the same location.

The map shows the predominance of high yield aquifers north of the Ohio River and along its channel. The only high yield areas south of the Ohio

River are in the Jackson Purchase Region of southwestern Kentucky and in the extensive sandstones and conglomerates running from southeastern Kentucky, through West Virginia, and into western Pennsylvania. The map is particularly useful for site planning and regional development. For example, industries and other groundwater users, who know their demand for groundwater, can restrict their regional site search to those areas capable of satisfying their needs. Additionally, the map can be used to delineate areas that should be aggressively protected from groundwater contamination.

An aquifer may contain water under either confined or unconfined conditions. In the unconfined situation (Figure 4), water percolates from the surface to the water table (i.e., level at which water pressure is equal to atmospheric pressure) unimpeded. Water only partly fills the aquifer, so the water table is free to rise and fall as a function of recharge and discharge. As shown in Figure 4, wells open to unconfined aquifers are known as water table wells and are indicative of the water table level in the surrounding aquifer.



UNCONFINED OR WATER TABLE CONDITIONS  
IN A NON-PUMPING SITUATION

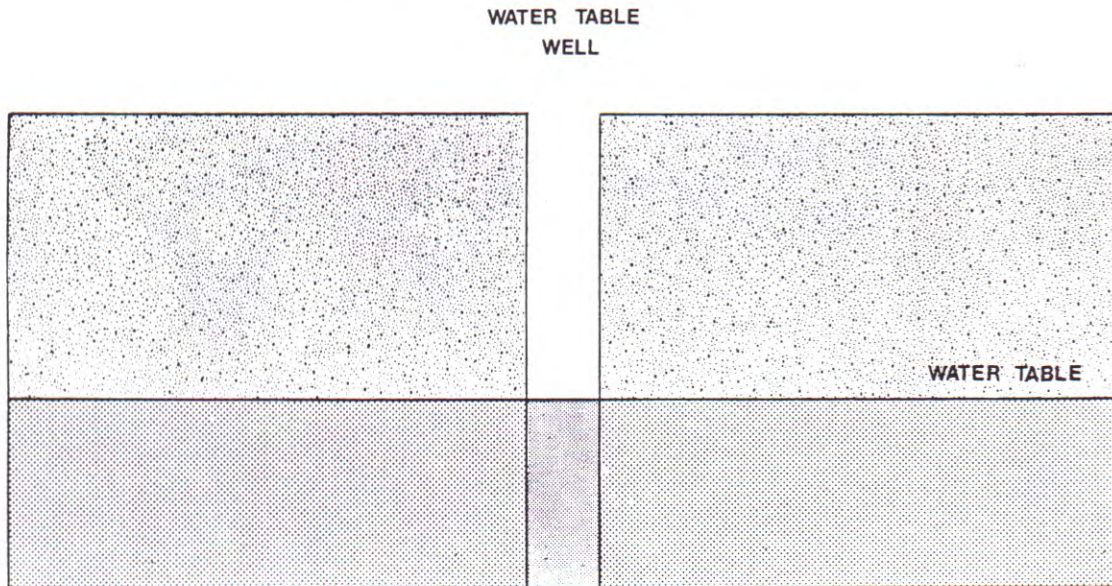


FIGURE 4

In confined or artesian aquifers, there is an impediment to downward movement (Figure 5). Characteristics influencing the movement are source or catchment area, confinement in the porous bed, impermeable beds above and below, dip of rocks, depth, etc. The confining layer, usually impermeable shale or clay in the Compact District, prevents water in the aquifer from freely rising or falling as a function of recharge. Because water in the recharge zone is at a higher elevation, pressure in the confined portion of the aquifer will exceed atmospheric pressure and water will rise above the top of the water-bearing unit. As shown in Figure 5,

this level will sometimes be above land surface, resulting in a flowing artesian well.

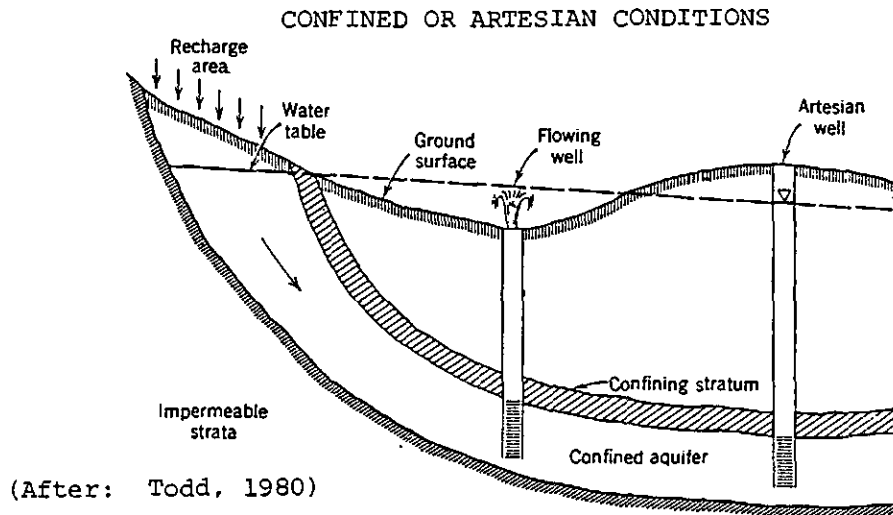
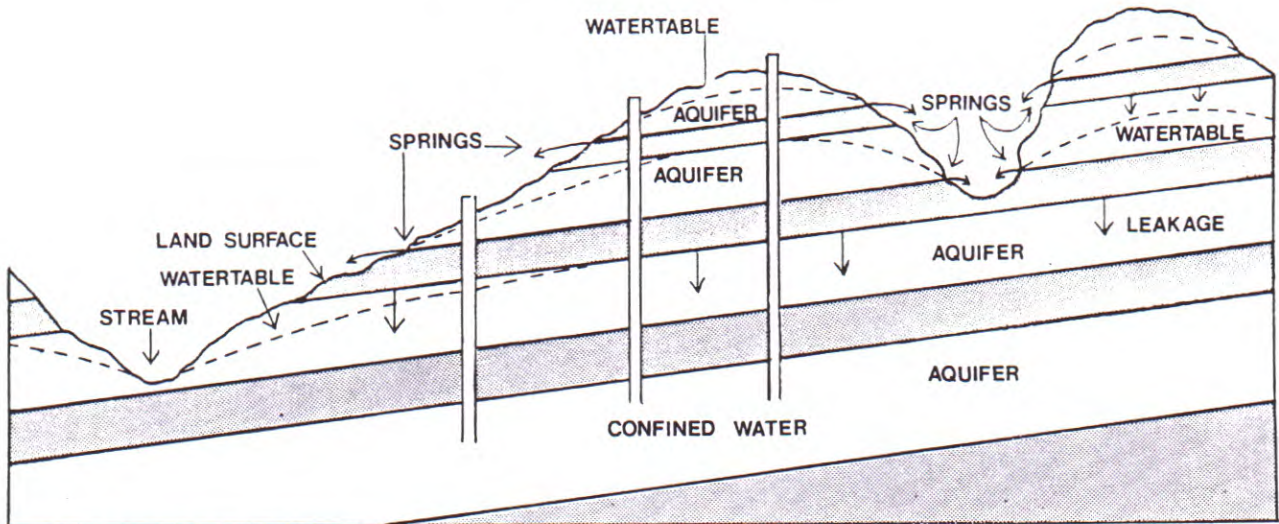


FIGURE 5

With respect to the occurrence of groundwater, the hydrogeologic configuration is seldom so simple as to foster the formation of a single water table. Aquifers may exist in any combination of conditions as described above. Owing to the differential porosity and permeability of stratigraphic units in the Ohio River Valley, complex multi-aquifer systems may exist (Figure 6).

# TYPICAL MULTI-AQUIFER SYSTEM



(After: Davis and DeWiest, 1966)

FIGURE 6

Glacial aquifers are, for the most part, limited to areas north of the Ohio River and along its channel. These aquifers, sometimes known as valley-fill aquifers, have a distinct, riverine geometry because they occupy the valleys of preglacial streams. These buried valleys are filled with sand and gravels to depths sometimes exceeding 200 feet, forming high yield aquifers capable of sustaining intensive groundwater development.

Because of the complexity of glacial and outwash processes, most valley-fill aquifers have discontinuous clay lenses and extensive layers of impermeable silt and clay associated with them

(Figure 7); producing complex flow systems where pressure conditions change rapidly in time and space.

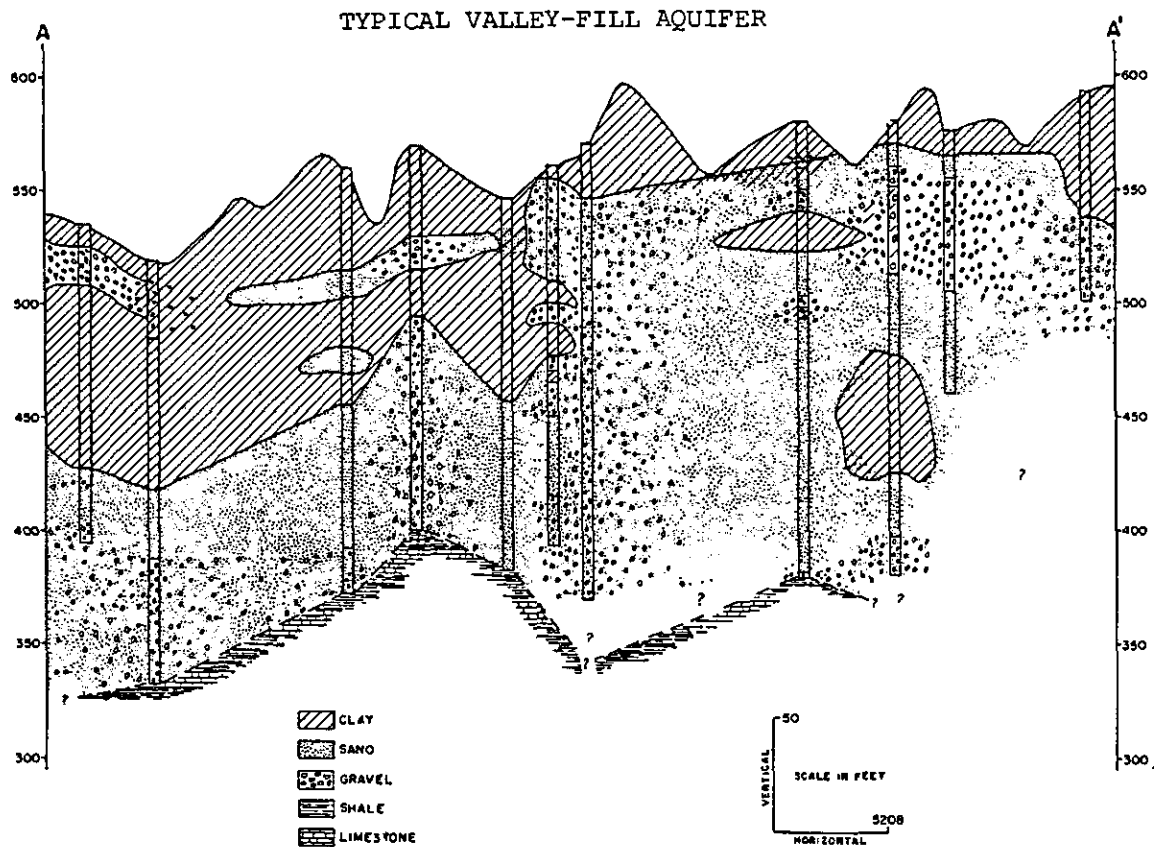


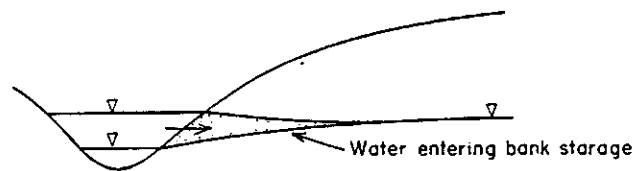
FIGURE 7

Many valley-fill aquifers have major streams flowing on their surface. If hydraulically connected to the groundwater, modern streams serve as a source of additional recharge should the normal hydraulic gradient be reversed by high stream flow (Figure 8) or heavy pumping (Figure 9). As shown in Figure 9,



heavy pumping induces surface water to flow down into the streambed, through the subsurface, and into a nearby well. Bank storage or recharge from high stream flow is only temporary, but induced recharge is always available as long as sufficient stream flow and an adequate hydraulic connection are maintained (Spieker, 1968).

GROUNDWATER RECHARGE DUE TO TEMPORARY  
BANK STORAGE



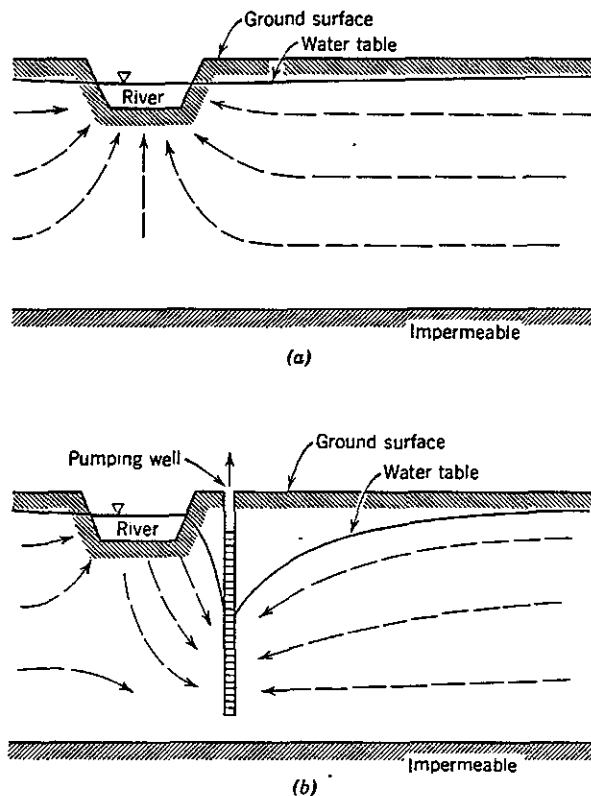
(From: Freeze and Cherry, 1979)

FIGURE 8



INDUCED RECHARGE RESULTING FROM A  
WELL PUMPING NEAR A RIVER

- (a) NATURAL FLOW PATTERN  
(b) FLOW PATTERN WITH PUMPING WELL



(From: Todd, 1980)

FIGURE 9

Worthy of special mention is the Ohio Valley aquifer, which parallels the Ohio River channel from Pittsburgh, Pennsylvania to Cairo, Illinois -- approximately 981 miles. Considering its limited areal extent, this is a prolific source of groundwater. The aquifer actually exists in a number of segments that are interrupted by tributary

valleys, and in some locations being displaced some distance from the present river course. In addition, the size has also been influenced by the high level navigation dams which have altered the storage of the companion terraces along the river. Bloyd (1974) estimates that about 4,500 billion gallons of water are available in storage. Because aquifer volume increases with downstream distance, more than 70 percent is stored in the lower third of the river (Table 1). With substantial induced recharge available all along the main stem, this aquifer has been intensively developed by large groundwater users.

TABLE 1		
WATER STORED IN THE OHIO VALLEY AQUIFER		
Reach of Ohio River	Stored Groundwater (Billions of Gallons)	Percent of Total
Upper Third	371	8.2
Middle Third	875	19.4
Lower Third	<u>3,255</u>	72.3
Total	4,501	
(Adapted from Bloyd, 1974)		

The other major aquifer comprised of unconsolidated sediments is the sands and gravels in the Jackson Purchase region of southwestern Kentucky

and extreme southern Illinois. This is a thick coastal plain deposit yielding large amounts of water close to the bedrock contact where very coarse grained sediments intermingle with the rubble of weathered bedrock (Davis, Lambert, and Hansen, 1973).

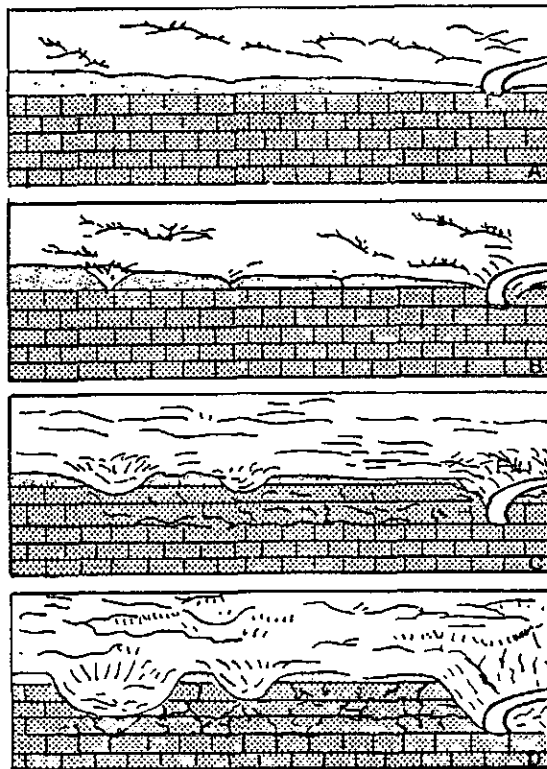
The remaining aquifers of regional significance are in extensive consolidated sediments (i.e., sandstones, conglomerates, limestones, and dolomites). These rocks were all formed in ancient seas. Some ancient seawater is believed to have been retained with these sediments during induration, and is known as connate water or brine. Some brine is very rich in trace elements and minerals and relatively close to the surface. These characteristics attracted early chemical industries to several sites in the Ohio River Valley (e.g., Charleston, WV; Barberton, OH; New Martinsville, WV; and others). Although some flushing has occurred, connate water exists in these rocks below the zone of active groundwater circulation (about 300-500 feet below the surface in most areas). To maintain a good water supply, it is imperative that wells only tap the zone of active circulation, and are not overpumped. Otherwise, connate brines will migrate upward to the well bottom.

Although clastic sedimentary rocks (e.g., sandstone and conglomerates) are composed of fragments of preexisting rock, their primary porosity is not particularly high because plugging or tightness is caused more often from clays and fines. Of a secondary nature is the cementing agent, usually calcium carbonate or ferric hydroxide which coats the grains and fills in much of the pore space in near surface rocks. For a clastic sedimentary rock to be a principal aquifer, it must have considerable secondary porosity. This can occur through faulting and jointing, but more extensive development is usually a result of stress relief and weathering (Wyrick and Borchers, 1981). Where many of these secondary openings can be intersected, yields will be substantially higher.

The carbonates (limestone and dolomite) differ from the coarse clastics in that they were formed in warm seas by chemical precipitation of calcium carbonate and magnesium carbonate or from the deposition of calcareous plants and animals. Carbonates are typically very dense and, in some cases, very thick. They are, however, quite soluble in acidic water. After forming cracks and crevices as a result of various stress or release factors, these openings and the inherent zones of weakness

along bedding planes are widened by aggressive water above, at, and below the water table (Davis and DeWiest, 1964). The result is the formation of karst topography (Figure 10), where groundwater flows in underground streams much like those on the surface.

#### DEVELOPMENT OF KARST TOPOGRAPHY



(From: Strahler, 1969)

FIGURE 10

Cave systems vary in their degree of flooding. The upper portions of the Mammoth Cave, extending from south-central Kentucky into southern Indiana, are only temporarily flooded. Caves and solution channels in this area are directly connected to



surface flow through numerous sink holes dotting the landscape. Water quickly drains to the groundwater base level (the Green River around Mammoth Cave) and the caves and smaller openings dry up -- offering no water to wells. In west-central Ohio and east-central Indiana, caves and solution openings are permanently saturated. This cave terrane was formed at a time of much lower drainage elevation or base level (Teays drainage) prior to glacial activity. The effect of the glaciers was to smooth out the topography and raise the base level by cutting off ridges and filling valleys with eroded material. Consequently, the water table rose to feed perennial streams and saturate what was once a dry cave system (Norris and Fidler, 1973). The cave is now a high yield aquifer.



## GROUNDWATER AVAILABILITY

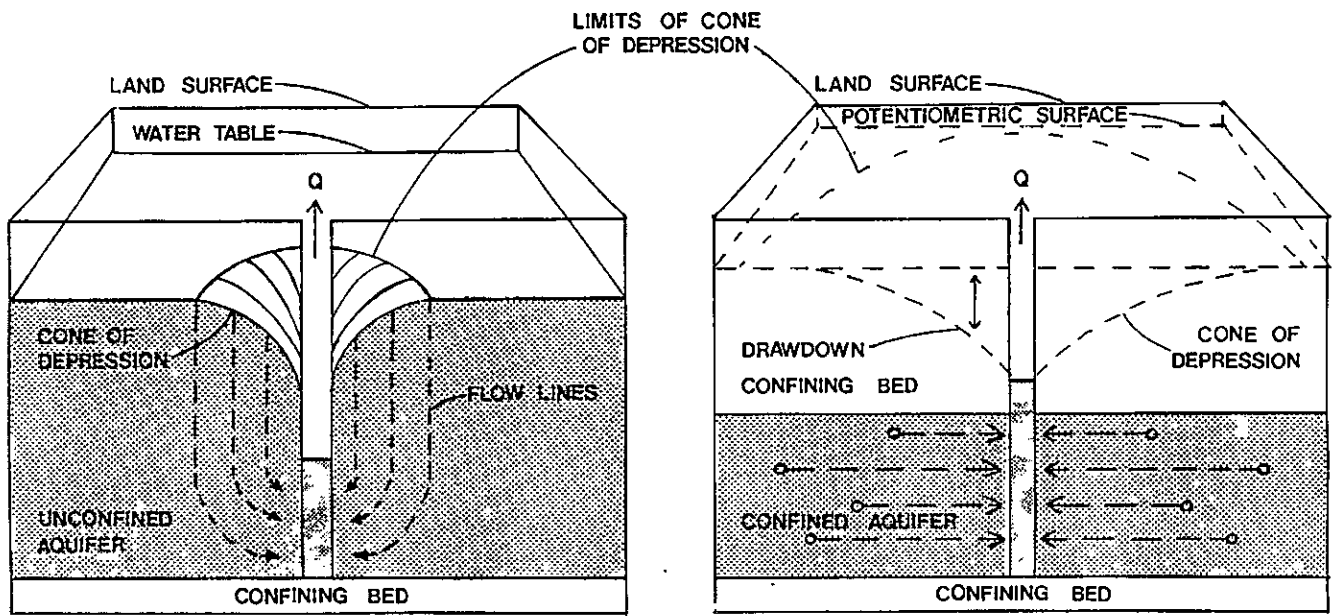
In developing groundwater resources, it is important to define aquifer characteristics and determine aquifer yield. This requires, among other information, a thorough knowledge of:

1. The position and thickness of the aquifer and confining beds;
2. The transmissivity (i.e., hydraulic conductivity x saturated thickness) and storage coefficient (i.e., the volume of water that is released from or taken into storage per unit surface area of aquifer per unit change in head normal to that surface);
3. The hydraulic characteristics of the confining beds;
4. The position and nature of aquifer boundaries; and
5. The location and amounts of withdrawal from existing wells, and the water budget of the basin.

Except for the last element, this information is best acquired by test drilling and conducting a pump

or aquifer test. An aquifer test involves pumping a test well at a high rate and noting its influence (i.e., drawdown) on nearby observation wells. In three dimensions, drawdown takes the shape of an inverted cone and is known as a cone of depression for either confined or unconfined conditions (Figure 11). Using a mathematical formula developed by Theis (1935) or subsequent derivatives thereof, the information is analyzed to define aquifer characteristics. These equations inextricably hinge upon a number of assumptions, summarized by Todd (1980). For a valid analysis, it is necessary to be aware of the assumptions and understand them fully.

CONE OF DEPRESSION DEVELOPMENT AROUND WELLS IN  
UNCONFINED AND CONFINED AQUIFERS



(From: Heath, 1983)

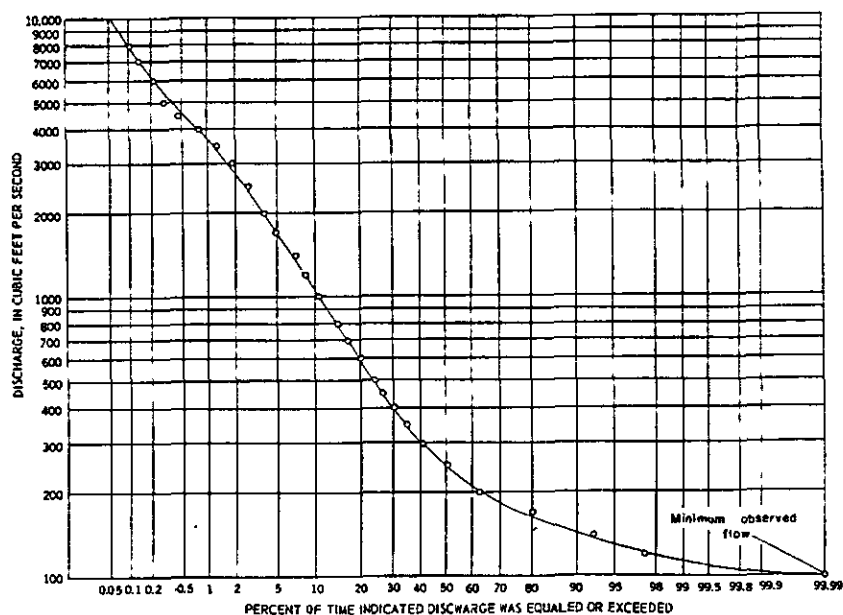
FIGURE 11

This type of detailed investigation is very expensive because of drilling costs. As a result, test drilling and an aquifer test are only used on a local basis by large groundwater users (e.g., industries and municipalities) who must be able to document the resource in order to secure their investment and, in many cases, comply with regulations. Test drilling and an aquifer test are also now widely used in groundwater contamination studies and aquifer restoration projects, where it is imperative to precisely define aquifer characteristics for design purposes.

For regional reconnaissance surveys, the hydrologist must depend upon more indirect methods such as water budgets or flow duration analysis to estimate groundwater resources. The United States Geological Survey (USGS), in cooperation with other agencies, maintains a network of stream gauging stations throughout the Ohio River Basin. Data from each station are used to develop a flow duration curve (Figure 12).



# FLOW DURATION CURVE



(From: Searcy, 1959)

FIGURE 12

On the abscissa is the percentage of time the indicated discharge (ordinate) was equaled or exceeded. Ninety percent flow is usually taken to represent base flow or groundwater discharge. Assuming that discharge is approximately equal to recharge, 90% flow is a crude estimate of groundwater recharge within the basin. Although natural groundwater recharge is not necessarily the amount available for withdrawal because of water available in storage and the recharge that may be induced from streams, it is widely recognized as a reliable indicator of groundwater availability.

A flow duration analysis using 1960 data published in Deutsch et al. (1969) was performed for each of the major subbasins in the Ohio River Basin (Table 2). The furthest downstream gauging station was used for unregulated subbasins. For regulated streams, an average of all unaffected upstream and tributary stations was used. This methodology was problematic for the main stem of the Ohio River, because data from unregulated tributaries completely neglect significant contributions from the Ohio Valley Aquifer. To compensate for this deficiency, it is assumed that 200,000 GPD recharges each square mile of the Ohio Valley Aquifer (Bloyd, 1974). The contribution of other glacial aquifers paralleling controlled streams are similarly neglected but are not considered to be significant in determining groundwater availability in their respective subbasins.

As shown in Table 2, subbasins dominated by unconsolidated aquifers have prolific groundwater resources. High base flow is a tribute to their exceptional ability to store and transmit water. Most subbasins dominated by bedrock aquifers do not store or transmit water as well. They are, nonetheless, regionally important because they extend into rural areas where groundwater is the primary,

Table 2

Estimates of Subbasin Recharge or Approximate Groundwater  
Availability Using Low Stream Flow Data

<u>Subbasin</u>	<u>Dominant Aquifer Material</u>	<u>Drainage Area (SQ MI)</u>	<u>90% flow<sup>2</sup> (CFS/SQ MI)</u>	<u>Recharge or Approximate Groundwater Availability (MGD)</u>
Allegheny	Unconsolidated Sediments	11,600	0.15 <sup>3</sup>	1,130
Monongahela <sup>1</sup>	Bedrock	7,310	0.10 <sup>3</sup>	470
Upper Ohio	Unconsolidated Sediments	13,200	0.07 <sup>3</sup>	3,240 <sup>4</sup>
Muskingum	Unconsolidated Sediments	7,980	0.11 <sup>3</sup>	570
Kanawha	Bedrock	12,200	0.21 <sup>3</sup>	1,660
Scioto	Unconsolidated Sediments	6,440	0.15 <sup>3</sup>	970
Big Sandy - Guyandotte	Bedrock	5,900	-	200
Big Sandy		4,210	0.05	140
Guyandotte		1,680	0.06 <sup>3</sup>	60
Great Miami	Unconsolidated Sediments	5,330	0.14 <sup>3</sup>	480
Middle Ohio <sup>1</sup>	Unconsolidated Sediments	8,850	0.05 <sup>3</sup>	2,060 <sup>4</sup>
Kentucky - Licking	Bedrock	10,500	-	360
Kentucky		6,870	0.07	310
Licking		3,660	0.02	50
Green	Bedrock	9,140	0.09	530
Wabash	Unconsolidated Sediments	32,600	0.12	2,530
Cumberland <sup>1</sup>	Bedrock	17,700	0.08 <sup>3</sup>	920
Lower Ohio <sup>1</sup>	Unconsolidated Sediments	12,500	0.01 <sup>3</sup>	2,580 <sup>4</sup>
Total				17,700

1 As defined in USGS Circular 878-A.

2 1960 Data from Deutsch et al. (1969).

3 Average of all subbasin gauge sites unaffected by regulation or diversion.

4 Adjusted upward assuming 200,000 GPD/SQ MI of recharge for the Ohio Valley Aquifer.

and sometimes only, source of water. For the Ohio Valley, there is about 17,700 million gallons per day (MGD) of available groundwater.

A better approach to estimate groundwater recharge is to construct a water budget for each major subbasin. Over the long term, precipitation (P) is approximately equal to runoff (R) plus evapotranspiration (EVT) plus groundwater recharge (GR):  $P = R + EVT + GR$ . Water budget analysis is usually limited to small subbasin studies because of the difficulty in precisely defining evapotranspiration over large areas. The National Weather Service Ohio River Forecast Center estimates evapotranspiration from conceptual watershed models for about 400 subbasin stations in the Ohio River Basin. More than 50% of the stations are uncalibrated, but there is sufficient data to construct water budgets for the Allegheny, Monongahela, Kanawha, Big Sandy-Guyandotte, and Scioto Subbasins. Until more stations are calibrated, flow duration analysis remains the most consistent means of estimating groundwater recharge for the entire Ohio River Basin.

It is useful to compare groundwater withdrawal with estimates of groundwater availability by major

subbasins (Table 3). In 1980, 2500 MGD were withdrawn in the Ohio River Valley. There is a striking variation in subbasin groundwater withdrawal. In those subbasins dominated by unconsolidated sediments (e.g., the Wabash and Great Miami Subbasins) there is tremendous usage of groundwater. In fact, the Wabash Subbasin alone accounts for more than 20% of total groundwater withdrawal in the Valley. On the other hand, most of the subbasins dominated by bedrock aquifers show very little demand for groundwater. Although other factors such as groundwater quality, surface water availability, and the degree of regional development are involved, the difference appears to be due to the availability of potable groundwater and the ease with which it can be developed to meet large needs.

Table 3 also shows that industry is the largest user of groundwater in the Ohio River Valley, and is of primary importance (i.e., constitutes more than 50% of total withdrawal) in the Monongahela, Upper Ohio, Kanawha, Big Sandy-Guyandotte, Scioto and Lower Ohio Subbasins. Public supplies account for about 30% of basin-wide withdrawal, and are of primary importance in the Great Miami and Green Subbasins. Rural use is of primary importance in the

Table 3

1980 Groundwater Withdrawal<sup>1</sup> (MGD) in the  
Ohio River Basin by Major Subbasin and Use

<u>Subbasin</u>	<u>Public Supply</u>	<u>Rural</u>	<u>Industrial Self-Supplied</u>	<u>Total</u>	<u>Percent of Available Groundwater Withdrawn</u>
Allegheny	39.2	42.1	51.2	132.5	12
Monongahela	3.7	14.4	196.7	214.8	46
Upper Ohio <sup>2</sup>	97.9	34.8	344.7	477.4	15
Muskingum	86.0	23.6	90.0	199.6	35
Kanawha	13.8	20.7	59.7	94.2	6
Scioto	21.0	12.9	56.0	89.9	9
Big Sandy--					
Guyandotte	10.0	16.4	55.9	82.3	41
Great Miami	184.2	21.3	69.6	275.1	57
Middle Ohio <sup>2</sup>	41.2	21.0	50.9	113.1	5
Kentucky -					
Licking	1.6	15.6	13.1	30.3	8
Green	11.8	7.9	0.3	20.0	4
Wabash	174.3	173.4	194.4	542.1	21
Cumberland	4.8	22.6	3.0	30.4	3
Lower Ohio <sup>2</sup>	44.7	17.1	130.6	192.4	7
Totals	734.2	443.8	1316.1	2494.1	14

Source: USGS (1984)

1 Figures do not include saline groundwater

2 As defined in USGS Circular 878-A



Kentucky Licking and Cumberland Subbasins, but is the least important use basin-wide.

In no case does present subbasin demand exceed 60% of estimated availability. Regionally, this seems to suggest that groundwater resources are not yet being used to their fullest extent. In fact, groundwater withdrawal is only about 14% of that available basin-wide. Actual subbasin percentages are, in many cases, substantially lower because of the ability to induce recharge from surface streams. Moreover, as long as sufficient streamflow is maintained in areas amenable to induced recharge, the groundwater resource is virtually unlimited (Spieker, 1968).

From time to time, temporary problems of local overdraft occur. When withdrawal exceeds recharge over long periods of time, groundwater is being mined. The net effect, although this may occur very gradually, is the continual lowering of groundwater levels which is now being experienced in the west-central and southwestern United States. As groundwater levels become more seriously depressed, other problems may arise. These include any combination of the following:

1. increased pumping costs;
2. interruption of water supplies;
3. land subsidence;
4. deteriorating water quality; and
5. legal disputes.

Groundwater disputes can have complex legal ramifications given the generally undefined nature of groundwater rights in the Compact District. The Signatory States adhere to riparian water rights, except for Kentucky and Virginia who have adopted some supplemental appropriative rights (Edison Electric Institute, 1984). For example, while continuing to adhere generally to riparian rights policy, Virginia has legislated administrative requirements for groundwater withdrawal permits for large industrial and commercial users in stipulated critical areas. For settling groundwater disputes in the absence of permits, the courts rely upon the American "Rule of Reasonable Use." This rule limits the landowner's withdrawal to amounts necessary for some useful or beneficial purpose in connection with the overlying land. Indiscriminate use is not permitted, and the common rights of landowners overlying the groundwater reservoir are recognized and protected against injury by those who would waste water. There is no accepted definition of reasonable

groundwater use, leaving the determinations of reasonableness to be made on a case-by-case basis (Tank, 1983).

## GROUNDWATER QUALITY

Groundwater quality has not received much attention until very recently, when much evidence (mostly anecdotal) began to suggest the possibility of a regional contamination problem. Industrial waste dumps, especially those designated for clean-up under the Comprehensive Environmental Response Contamination and Liability Act (CERCLA) or "Superfund," seem to receive the largest amount of publicity. Groundwater pollution emanates from the inappropriate use and disposal of chemicals and waste products of all kinds. Thus, contamination occurs in all types of cultural landscapes.

Defining "natural" groundwater quality continues to be the major concern of groundwater investigations. Chemical analyses tend to focus on primary constituents (i.e., chemical species generally occurring in concentrations exceeding 5 mg/l), a few secondary constituents (i.e., chemical species generally occurring in concentrations exceeding 0.1 mg/l), and a few physical properties in the absence of a specific contamination complaint. The chemistry of routinely measured constituents and

physical properties (Hem, 1970) and their sources or causes and significance (Table 4) are well understood. Unless one of these parameters is affected, a pollution problem may go undetected by routine sampling. For example, synthetic organic compounds are a common groundwater contaminant (Dyksen and Hess, 1982) that cannot be detected with the usual suite of measurements. The cost of collection and analysis of water is substantial enough to limit the number of parameters routinely monitored. As a result, several indicator parameters have been developed.

TABLE 4

ROUTINELY MEASURED CONSTITUENTS AND PHYSICAL PARAMETERS  
OF GROUNDWATER: THEIR SOURCE OR CAUSE AND SIGNIFICANCE

Constituent or physical property	Source or cause	Significance
Silica ( $\text{SiO}_2$ )----	Dissolved from nearly all rocks and soils. Generally in small amounts from 1 to 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high-pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)-----	Dissolved from nearly all rocks and soils. May be derived also from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and many other processes. Federal drinking-water standards state that iron and manganese together should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)-	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark-brown or black stain. Federal drinking-water standards provide that iron and manganese together should not exceed 0.3 ppm.
Calcium (Ca) and magnesium (Mg)	Dissolved from nearly all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium found in large quantities in some brines. Magnesium occurs in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming. (See Hardness.) Waters low in calcium and magnesium desired in electroplating, tanning, dying, and textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from nearly all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate ( $\text{HCO}_3$ ) and carbonate ( $\text{CO}_3$ ).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate ( $\text{SO}_4$ )----	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Generally in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is beneficial in the brewing process. Federal drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)---	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal drinking-water standards recommend that the chloride content should not exceed 250 ppm.
Fluoride (F)---	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, according to the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (See Maier, 1950, p. 1120-1132.)

TABLE 4  
(continued)

Constituent or physical property	Source or cause	Significance
Nitrate (NO <sub>3</sub> )---	Decaying organic matter, sewage, and nitrates in soil.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 ppm of nitrate (NO <sub>3</sub> ) may cause a type of methemoglobinemia in infants, sometimes fatal. Water of high nitrate content should not be used in baby feeding. (See Maxcy, 1950, p. 265, App. D.) Nitrate is helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids.	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Federal drinking-water standards recommend that the dissolved solids should not exceed 500 ppm. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as CaCO <sub>3</sub> .	In most waters nearly all the hardness is due to calcium and magnesium. The hydrogen ion and all the metallic ions other than the alkali metals also cause hardness.	Causes consumption of soap before a lather will form, and deposition of soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Waters having hardness up to 60 ppm are considered soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; more than 200 ppm, very hard.
Specific conductance.	Ionized mineral constituents in the water.	Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25°C.
Hydrogen-ion concentration (expressed as pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. The pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters also may attack metals.
Temperature---		Affects usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuation in water temperature. Ground water from moderate depths generally is nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases on the average about 1°F with each 50- to 100- foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large, depending on the depth of water, but do not reach the extremes of air temperature.

(From: Hopkins, 1963)



One of the indicators of organic contamination now being used is total organic carbon (TOC). Under normal conditions, groundwater is relatively free of organic carbon. Therefore, elevated TOC levels would be indicative of organic contamination. The technology for measuring TOC has been available for some time, but there has always been a problem with losing volatile organic carbon (VOC). Barcelona (1984) has developed a modified TOC procedure that traps VOC, permitting more complete characterization of groundwater organic carbon content.

TOC has the potential to be a good indicator parameter for organic groundwater contamination, avoiding costly gas chromatography (GC) and mass spectrometer (MS) analyses. The Miami Conservancy District, in cooperation with the USGS, has conducted a TOC reconnaissance survey of the Great Miami Aquifer (Evans, 1977). The results successfully defined several potential contamination areas, demonstrating the value of TOC as a screening device.

Base line or typical groundwater quality should be established before considering the possibility of contamination. This is best done on a local scale, but the regional scale of this study requires some generalization. Groundwater quality information was

abstracted from the literature and organized by major subbasin and principal aquifer. Due to a lack of data, not every principal aquifer in every subbasin is represented in the analysis. Some of the principal aquifers may transcend topographic divides, permitting groundwater to flow from one subbasin to another. Consequently, groundwater quality for one subbasin principal aquifer may not be completely independent of the same aquifer in adjacent subbasins. The groundwater quality data predate 1970 and are limited to routinely measured parameters. All available data were included in the analysis, except where the procedures or the results appeared questionable or where there was obvious contamination from human sources.

Base line data can be statistically established in several ways. Since natural variability is sometimes extreme, the USGS commonly presumes that median values approximate typical groundwater quality. For convenience, we have chosen to report arithmetic mean values (Table 5). The difference between the arithmetic mean and median is not expected to be great for most parameters.

## GROUNDWATER CONTAMINATION

Based on the limited number of parameters in Table 5, Table 6 indicates there are problems with high iron, manganese, and hardness. Groundwater from most subbasin principal aquifers exceeds U.S. Public Health Service (US PHS) standards (US PHS, 1962) for iron and manganese and the USGS "very hard" classification. These problems have been reported before (Deutsch, Dove, Jordan, and Wallace, 1969). While believed to be the result of natural geochemical processes, these problems may not be completely divorced from human impact. There is evidence (e.g., the closing of Westview Water Authority Wells on Neville Island because of organic chemical contamination from a near-by waste disposal lagoon (Westview Water Authority, 1975), the closing of Zanesville City Wells along the Muskingum River because of organic chemical contamination from a waste disposal pit on the other side of the river (Ohio EPA, 1984), the Chem-Dyne hazardous waste clean-up along the Great Miami River, and others) to suggest that there are many localized contamination problems. Although believed to be of limited areal extent, these incidents, if not properly redressed, have the capacity to contaminate large aquifers of prime importance to the Ohio Valley.

SUBBASIN PRINCIPAL AQUIFERS AND SOURCE  
OF GROUNDWATER QUALITY DATA:  
A KEY TO TABLES 5 AND 6

- 1 Allegheny Subbasin: glacial outwash (Crain, 1966; Frimpter, 1974; Gallaher, 1973; Legette, 1957; Newport, 1973a; Newport, 1973b; Poth, 1973; Schiner and Gallaher, 1979; and Schiner and Kimmel, 1976).
- 2 Allegheny Subbasin: Pocono Group (Crain, 1966; Frimpter, 1974; Gallaher, 1973; Legette, 1957; Newport, 1973a; Newport, 1973b; Poth, 1973; Schiner and Gallaher, 1979; and Schiner and Kimmel, 1976).
- 3 Monongahela Subbasin: Pottsville Group (Ward and Wilmoth, 1968).
- 4 Upper Ohio River Subbasin: Quaternary alluvium and glacial outwash (Adamson, Graham, and Klein, 1949; Friel and Bain, 1971; Jeffords, 1945; Legette, 1957; Ohio Environmental Protection Agency, 1981; Poth, 1963; Poth, 1973a; Poth, 1973b; Schiner and Gallaher, 1979; Schiner and Kimmel, 1976; Van Tuyl and Klein, 1951; and Wilmoth, 1966).
- 5 Upper Ohio River Subbasin: sedimentary rocks of Mississippian age; primarily the Burgoon Sandstone, Cussewago Sandstone, Berea Sandstone, and the lower member of the Shenango Formation (Adamson, Graham, and Klein, 1949; Friel and Bain, 1971; Jeffords, 1945; Legette, 1957; Ohio Environmental Protection Agency, 1981; Poth, 1963; Poth, 1973a; Poth, 1973b; Schiner and Gallaher, 1979; Schiner and Kimmel, 1976; Van Tuyl and Klein, 1951; and Wilmoth, 1966).
- 6 Muskingum Subbasin: glacial outwash (Dove, 1960).
- 7 Muskingum Subbasin: sedimentary rocks of Mississippian and Pennsylvanian age; primarily the Berea Sandstone but may include the Allegheny and Pottsville Formations (Dove, 1960).

cause problems for years depending on the solubility of the material. (See Case Studies, page 52.)

Sanitary wastes from sewage disposal systems (i.e., septic tanks, sanitary sewers, and wastes applied to the land surface as a soil conditioner) can be a source of pollutants (both chemical and biological) in areas either unsuitable for disposal or within the recharge zone of a nearby well. Various household and industrial grade chemicals are commonly released into disposal systems not designed for their treatment and eventually find their way either directly into groundwater or into surface streams where they may subsequently contaminate groundwater through induced recharge (Norris, 1967 and Spieker, 1968).

Urban runoff, charged with road wastes (e.g., road salts), seepage from uncontained raw material stockpiles (e.g., salt, coal), and minor chemical spills (e.g., gasoline), is a source of contamination where urban activities are situated on a sensitive recharge area. The problem is accentuated where wells are of poor construction (poorly sealed wells allow surface runoff to directly flow into the subsurface) or where contaminated runoff is artificially recharged to an aquifer.

Agricultural activities can introduce contaminants over wide areas, where fertilizers and pesticides are applied in excess of recommended application rates. With the advent of chemigation (i.e., the application of agricultural chemicals via irrigation water), groundwater beneath irrigated land is particularly susceptible to contamination. Feedlot runoff, charged with nitrates and other pollutants, can also be a serious problem for shallow near-surface aquifers and where wells are of poor construction.

Mining (including oil and gas drilling) and other excavation works can create pollution problems for groundwater. Mining frequently takes place in or through an aquifer or a bed hydraulically connected to an aquifer. Aside from disrupting groundwater flow, mining can introduce contaminants into groundwater by making previously isolated elements available for chemical alteration or solution in the presence of water (e.g., acid mine drainage). Furthermore, abandoned mines (especially gravel pits) and wells can and often do serve as inappropriate waste receptacles.

## GROUNDWATER CLEANUP

Locally contaminated groundwater is not an irreparable situation. There is a rapidly developing technology for containing localized contamination and restoring affected aquifers to acceptable drinking water standards. Different conditions require different techniques, but all cleanup operations have three basic objectives -- containment, treatment, and monitoring.

Containment involves sealing the affected surface area to prevent further migration of contaminants into groundwater, and stabilization of the contaminant plume. Construction of physical barriers (e.g., grout curtains, sheet pilings, slurry cut-off walls, etc.) tied to a shallow (less than about 100 feet) impermeable stratum can stop plume movement. For deeper situations, it is necessary to use hydrodynamic control (Figure 13). By operating strategically placed production and recharge wells, the water table is leveled out, stopping plume movement. Containment is a very expensive temporary option. It must be followed by further remedial efforts to alleviate the contamination problem.



# HYDRODYNAMIC CONTROL OF A CONTAMINATION PLUME

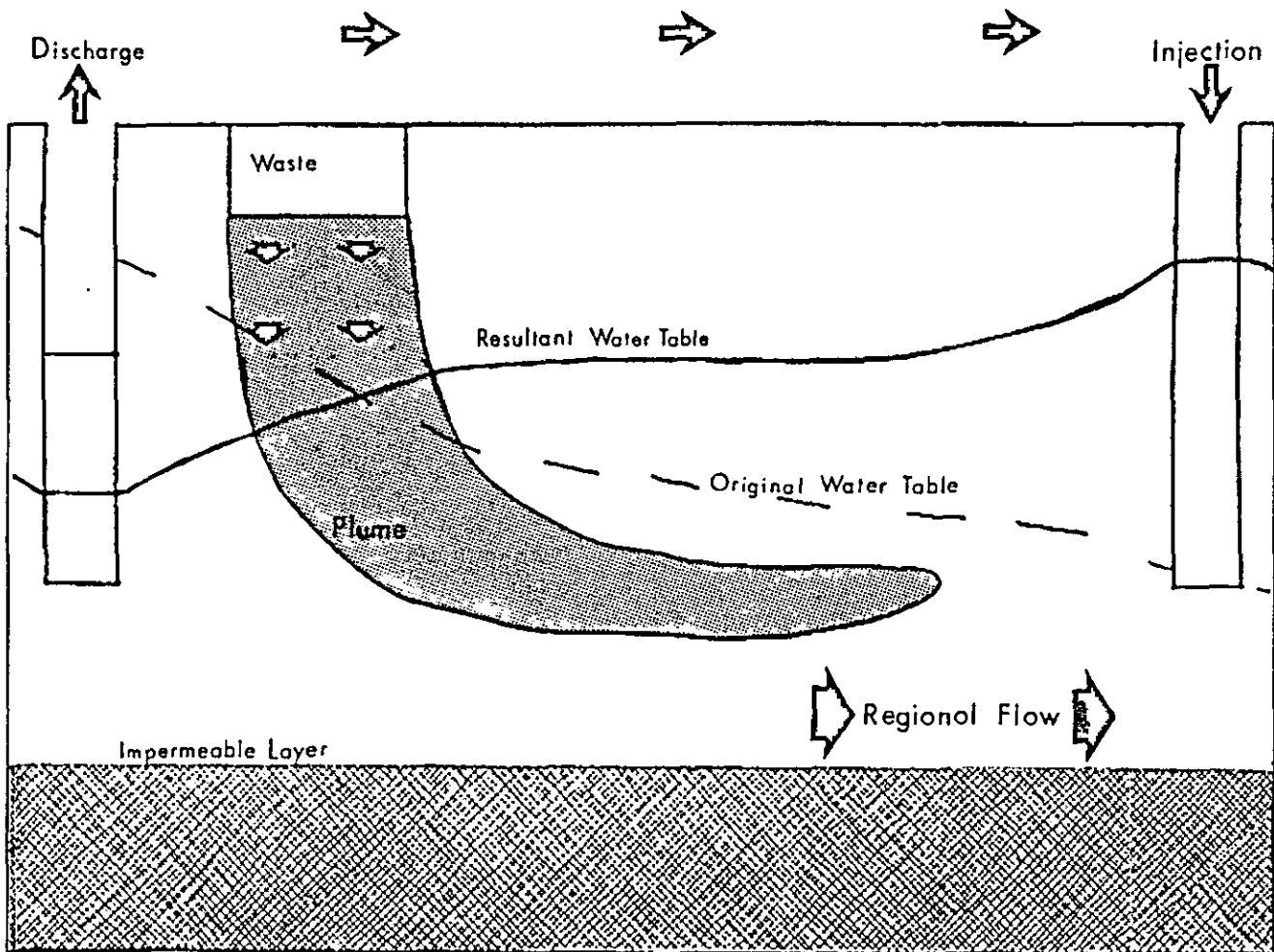


FIGURE 13

Contaminated groundwater may be treated in situ or removed to conventional treatment equipment on the surface. In situ treatment involves injecting chemical or biological treatment agents directly into the plume or by constructing a permeable treatment bed (limited to depths less than 100 feet) to be encountered by the plume (Figure 14). Quality

control for in situ operations is difficult and their widespread effectiveness and success is yet to be documented.

#### PERMEABLE TREATMENT BED

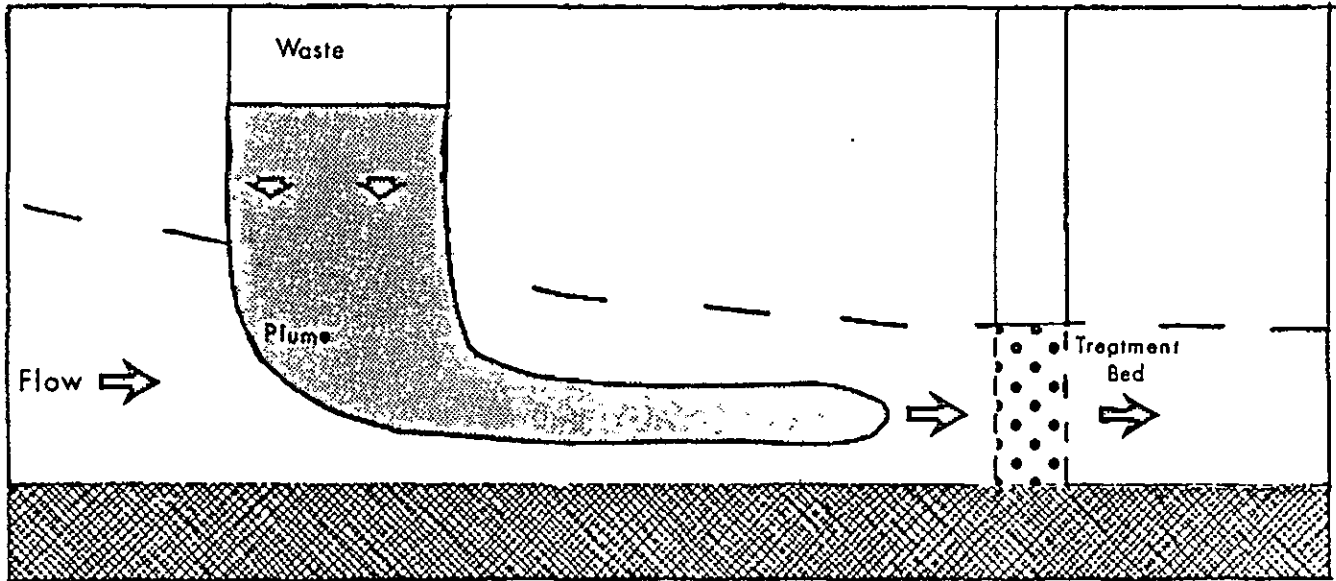
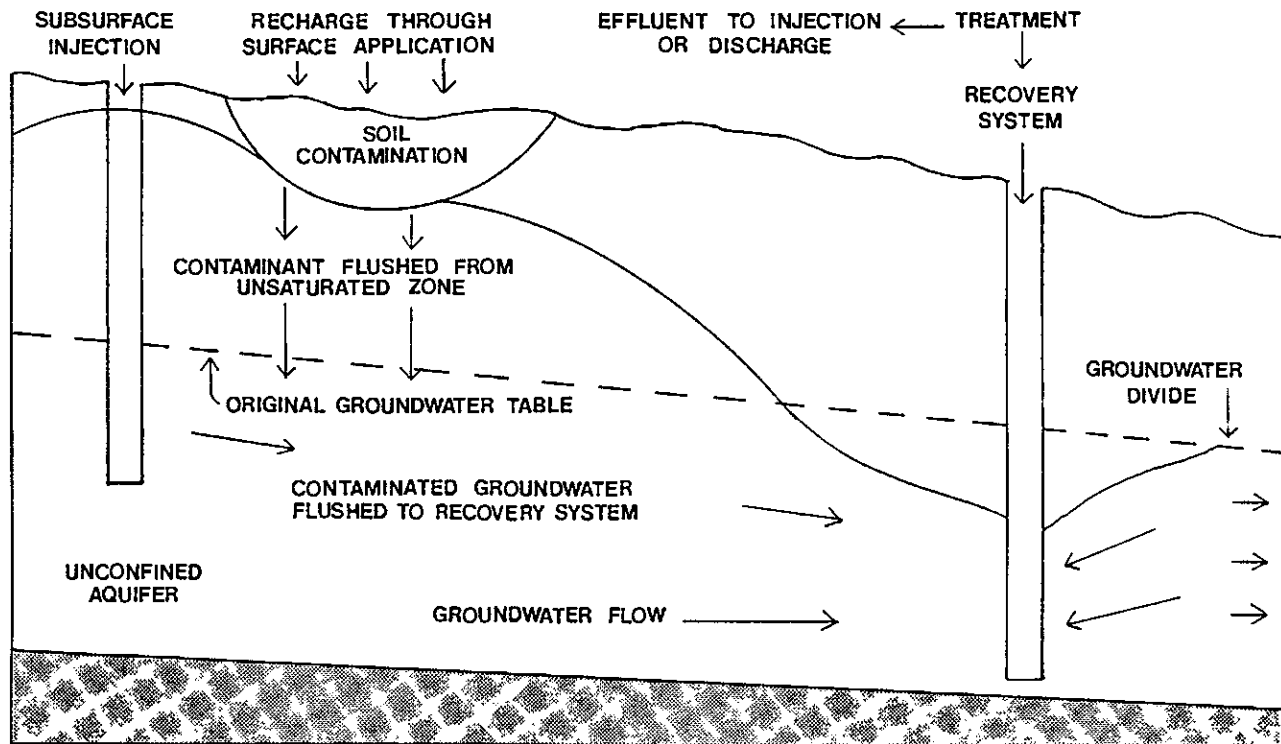


FIGURE 14

Removing groundwater to the surface for conventional treatment (e.g., sand filtration, air stripping, granulated activated carbon, etc.) is proven technology. The most popular method is hydrodynamic control (Figure 15). The rate of pumping from the production wells is adjusted so that the plume is intercepted and contaminated water is delivered to the surface for treatment. Once treated to an acceptable level, the water may be recharged upgradient of the source to maintain hydrodynamic control, recharged through surface application to

flush contaminants from the unsaturated zone, discharged to a storm sewer or receiving stream, or any combination of these methods.

# HYDRODYNAMIC CONTROL WITH A CONVENTIONAL TREATMENT SYSTEM ON THE SURFACE



(Adapted from: Quince and Gardner, 1982)

FIGURE 15

An integral element in the overall clean up process is systems and groundwater monitoring. The components of the clean up system must be continually monitored to assure quality control. It is also very important to monitor groundwater in situ during the clean up process as well as for month, or even years

after, to assess project effectiveness and detect any potential complications.

### Case Histories

The contamination of groundwater and need for monitoring is illustrated by an incident that occurred from a railroad accident in February, 1977, near Guilford, Indiana. Some 34,000 gallons of acrylonitrile (AN) was spilled onto the land surface from a railroad tank car and a large portion entered the groundwater. Monitoring by the Indiana State Board of Health revealed that concentrations as high as 6,600 ppm were present in the fourteen observation and four production wells drilled to monitor and reduce the level of AN in the groundwater. The water from the production wells was treated before discharge to the stream from February to December, 1977, at which time the level of AN was reduced to <0.05 mg/l. The relative ease that the AN entered the groundwater and the length of time needed (and associated cost) to reduce the concentration to acceptable levels illustrates the need to provide safeguards against contamination of the underground stata from the land surface and the importance of monitoring.

Contamination of a groundwater aquifer which serves as a source for a public water supply is illustrated in another case history. The West View Waterworks, located on two islands in the Ohio River downstream from Pittsburgh, Pennsylvania, used some 19 production wells as a source of water. In 1975, an oily odor was detected in eight of the wells, and studies were initiated to determine the source of the organic contamination. Wells serving two industries in same vicinity were also found to contain the same type of organic contamination. A series of observation wells were drilled to monitor the movement of the groundwater in the vicinity of the production wells. Organic (GC/MS) analysis by the waterworks and the Commonwealth of Pennsylvania suggested that the source of the contamination was a liquid waste lagoon in the vicinity of the wells since many of the organic compounds were common to both the groundwater and the lagoon. Residual contamination continued to move in the aquifer long after corrective action was taken to control the source. It is projected that years will be required to purge the groundwater system of the organics now present. Continued pumping of some production wells became necessary as a preventative measure to contain contamination in the affected area.

## CONCLUSIONS

The following conclusions are based on the data and information compiled during this survey.

1. Many misconceptions about the nature of groundwater continue to exist.
2. Based on potential yield, most of the groundwater resources are situated north of the Ohio River and along its channel.
3. The Ohio Valley Aquifer, paralleling the Ohio River from Pittsburgh, Pennsylvania to Cairo, Illinois, is one of the most important principal aquifers in the Ohio River Basin. An estimated 4500 billion gallons of water are in storage, and more than 30% of total groundwater withdrawal in the Ohio River Basin is from this aquifer.
4. Much geologic, hydraulic, and other physical information on aquifers is available but is somewhat difficult to assemble.

5. Stream flow duration analysis indicates the availability of approximately 17,700 MGD groundwater in the Ohio River Valley. It should be noted that groundwater use may offset stream flow, particularly in the stream valleys. As groundwater pumpage increases, base stream flow may be reduced, especially if the groundwater use is highly consumptive.
6. Groundwater is currently underutilized in the district. In 1980, 2500 MGD of groundwater were withdrawn in the Ohio River Basin, representing about 14% of available groundwater and about 7% of all freshwater withdrawn (excluding hydroelectric power).
7. Generally, groundwater rights are not well defined. The Signatory States adhere to riparian water rights, with Kentucky and Virginia (limited to large users in stipulated critical areas) having adopted supplementary appropriative rights requiring groundwater withdrawal permits.



8. Primary drinking water standards continue to be the major concern of groundwater monitoring efforts. Little data concerning trace organics and trace metals exist in the literature and data systems (e.g., STORET).
9. Average groundwater quality information indicates that iron, manganese, and hardness exceed US PHS drinking water standards in many of the subbasin principal aquifers.
10. Many instances of local groundwater contamination have been identified from the literature, particularly in connection with the hazardous waste control programs. Although believed to be of limited areal extent, many have the potential to contaminate large aquifers, if not properly redressed.
11. The extent of groundwater pollution (particularly incidents involving organic chemicals) in the principal aquifers is not known.



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