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AN APPRAISAL OF THE GROUND-WATER RESOURCES OF THE SUSQUEHANNA RIVER BASIN IN NEW YORK STATE

BY

ESTE F. HOLLYDAY

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AN APPRAISAL OF THE GROUND-WATER RESOURCES OF THE SUSQUEHANNA RIVER BASIN IN NEW YORK STATE

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INTRODUCTION

This report on the ground-water resources of the New York State section is the fourth in a series of four interim reports on the ground-water resources of the Susquehanna River basin. It is intended to serve the specific needs of both the Corps of Engineers, U. S. Army, and the Federal Water Pollution Control Administration for interim ground-water information as well as the general needs of the other Federal and State agencies participating in the comprehensive study of the basin. The information is preliminary and subject to final revision as part of the final report on the entire basin. The four arbitrary subdivisions of the Susquehanna River basin for which reports have been prepared are: (1) the lower Susquehanna River basin, (2) the Juniata River basin, (3) the upper Susquehanna River basin in Pennsylvania, and (4) the Susquehanna River basin in New York State, which is covered by this report. A final report will be prepared on the ground-water resources of the entire basin.

The comprehensive study of the water and related land resources of the Susquehanna River basin was authorized by the Congress of the United States in October 1961, and the tasks of preparing a report and coordinating the work being done by others in support of the study were assigned to the Corps of Engineers. The comprehensive study is being conducted by 15 Federal departments and independent agencies in cooperation with the States of New York, Pennsylvania, and Maryland. Topics of investigation within the study include economics, flood control, water supply, water quality, recreation, generation of electric power, navigation, fish and wildlife conservation, water retardation including water and soil conservation, drainage, irrigation, and salinity control. This report is most pertinent to water supply, water quality, and irrigation.

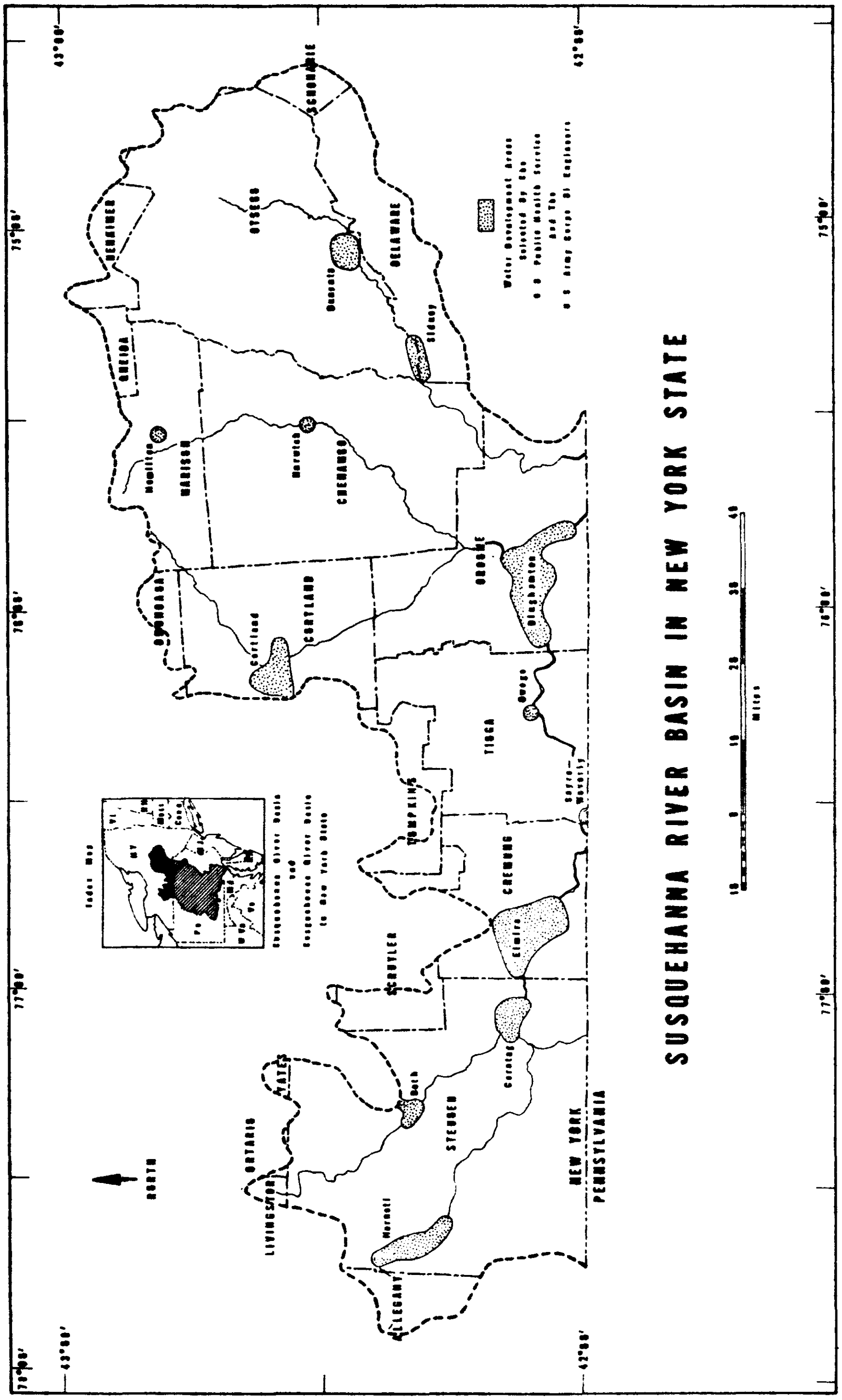

Figure 1.--Map showing designated water-development areas in the Susquehanna River basin in New York State.

Congressional guidelines relative to planning for the conservation and development of water and related land resources stress physical and economic efficiency. Senate Document 97 in Part III, Section B, states that planning shall be on a fully comprehensive basis so as to consider all needs and all possible uses of water, water-quality control, and alternative means of accomplishing all possible uses. Senate Document 97 further states that the choice between alternatives shall be on the basis of the cost of any proposed project in relation to the benefits received. The Corps of Engineers and the Federal Water Pollution Control Administration are jointly determining the present and future water requirements in water-development areas shown on figure 1. The participating Federal and State action agencies are responsible for drafting plans for developing the most economically feasible source of water in these areas.

Purpose

The U. S. Geological Survey has the sole responsibility in the comprehensive study for providing basin-wide ground-water information to the action agencies. The consideration of alternative combinations of means for water supply and water-quality control, as set forth in Senate Document 97, requires that comparison be made between the use of surface water and ground water. The Geological Survey has been assigned the responsibility of investigating the ground water of the basin to provide the facts necessary for the action agencies, who have made their own surface-water appraisal, to make such a comparison. Also, in response to requirements expressed in Senate Document 97, the Geological Survey has been assigned the responsibility of determining the cost of ground-water development as an alternate source in the absence of a surface-water project.

The purpose of this report is to present the geologic, hydrologic, and economic parameters necessary for a preliminary evaluation of the role of ground water in the formulation of the comprehensive plan for the conservation and development of water and related land resources of the Susquehanna River basin in New York State. The appraisal of the ground-water resources is presented in terms of the variability in quantity, cost, quality, and areal distribution.

Scope

This report is limited in scope to answering the following questions about ground water: (1) How much water is available? (2) What does it cost to develop? (3) What is the chemical and physical quality of the water? (4) What is the areal distribution of each aquifer? (5) What is the variability that can be expected in values of quantity, cost, and quality? Answers to the first question are reported as the yields that may be expected from individual wells in each aquifer. Answers to the second question are reported as the cost of ground water delivered at the land surface from individual wells in each aquifer. Answers to the third question are reported as the concentrations of chemical constituents and measurements of the physical properties of samples of well water collected from each aquifer. Answers to the fourth question are given in the form of a regional map of aquifers (fig. 5) to which quantity, cost, and quality are keyed. Finally, answers to the fifth question about ground water are given in the form of the 75 percent to 25 percent range in probability-of-occurrence of the values of quantity, cost, and quality.

The generalized estimates of the variability in quantity, cost, and quality of ground water given in this report are intended for use only to determine if ground water is likely to be the most economical and suitable source of water supply in any given area. The actual decisions concerning feasibility and the cost benefits of ground water and their comparison with alternate sources of supply will not be made by the Geological Survey. This report presents only the facts upon which these decisions may be based.

The ground-water costs given in this report are based upon the design and operation of hypothetical wells, which in turn are based upon a series of arbitrary assumptions. The ground-water costs are specifically developed for comparison with surface-water costs being developed by other agencies. Because of this general treatment, the costs given are not directly applicable to nor intended for use in the planning and design of any ground-water development project. The planning, design, and construction of specific ground-water supply systems require hydrologic and geologic data of the immediate localities and also the services of specialists such as consulting engineers, geologists, and well drilling contractors.

Acknowledgments

During field reconnaissance in the summer of 1965, the New York State Department of Highways provided logs of highway test borings at bridge structures within the main valleys. The New York State Department of Health provided well data and quality of water data from public water supplies within the basin. Several municipal water officials and well drilling contractors were most helpful in supplying well data and information on local ground-water conditions.

Mr. Allan D. Randall, Mr. Robert D. MacNish, and Mr. Robert G. LaFleur, New York District, Water Resources Division, U. S. Geological Survey, discussed geology and ground-water conditions in the basin with the author and provided hydrologic and geologic data and hydrogeologic maps for valley areas of the basin east of Corning, N. Y.

The report was prepared under the supervision of Paul R. Seaber, Project Chief, Susquehanna River basin project.

SUMMARY OF GROUND-WATER RESOURCES

Importance of Ground Water

Ground water plays a vital role in the hydrologic cycle, which is the endless circulation of water from the ocean as the primary reservoir to the atmosphere, to the land, and back to the ocean.

A major part of the role ground water plays in the hydrologic cycle concerns the intimate interrelationship between ground water and surface water. In humid areas, discharge from ground-water storage through springs and stream beds maintains the flow of streams during periods of little or no precipitation. In such areas, geology determines the dependability of streamflow. Hence, a correlation can be made between streamflow characteristics and the water-yielding characteristics of the rocks of a basin. Basins whose streams have flashy runoff characteristics are usually underlain by rocks of lower capacity to receive and to temporarily store water than rocks underlying basins whose streams have a more uniform flow. For example, streams underlain by shale tend to have flashy runoff characteristics compared to streams underlain by unconsolidated sands.

Most of the streams in the Susquehanna River basin are gaining streams; that is, water moves from the ground-water reservoir to the surface streams. This condition may be reversed in some instances, and water may move from the stream to the ground-water body. In extreme cases, wells pumping along a stream may intercept such quantities of water that the streamflow will cease.

The quality of streamflow, as well as the quantity, is related to the contiguous ground-water reservoir. If the major part of streamflow is base flow from ground water, the water in the stream will usually be relatively high in dissolved solids and low in suspended solids. On the other hand, if most of the streamflow is from overland runoff, the water in the stream will usually be relatively low in dissolved solids and high in suspended solids.

At one time ground water could be thought of as widely distributed and generally rather easily obtained substance whose principal usefulness lay in meeting small-scale domestic and stock requirements in rural areas and in small towns. Later, community wells were drilled to replace polluted individual wells and to supply residents of those parts of the towns where ground water was difficult to obtain. Commercial and industrial establishments began to drill their own wells for reasons of economy.

Around the turn of the century and for some years thereafter, ground water was not generally utilized as a source to meet large demands. However, as techniques of well construction and pump design improved, it became possible in many areas to obtain needed supplies of water from wells at a cost in time, money, and initial materials less than that required for development of a surface-water source.

Ground water has developed from a quantitatively minor (though critically important) source for domestic and small public supplies to a source supplying something like one-sixth to one-fifth of the national water-supply requirements (McGuinness, 1963, p. 111). Ground water reservoirs will not only continue to be a major source for meeting withdrawal requirements, but are emerging as a medium for storing even larger quantities of surplus streamflow for cyclic withdrawal as a phase of multipurpose water management.

Where locally available in suitable quantity and quality, ground water provides a source of water without the necessity of long transmission lines. Even where the available supplies of ground water may not equal the ultimately anticipated requirements, it may be advisable to develop ground water locally to meet the needs until larger sources become economically feasible. The ground-water sources developed earlier can then be used as a supplementary supply.

Ground water may be preferred to surface waters because of its relatively uniform temperature, quantity, and quality throughout the year. Currently about half the population of the Susquehanna River basin in New York State is estimated to use water obtained from underground sources. In this area, about 90 municipalities depend upon ground water for all or part of their supply. The total quantity of ground-water use may be expected to increase even as major urban supplies of surface water are developed.

Ground water is one of the earth's most widely distributed resources and one of its most important. Nevertheless, certain disadvantages are inherent in large-scale development of ground water (McGuinness, 1963, p. 111). Among these disadvantages are: (1) a general lack of knowledge as to occurrence, movement, distribution, availability, and the cost of the studies required to supply the desired knowledge; (2) costs associated with drilling wells and pumping them instead of collecting water by gravity flow; (3) complexities in management imposed by water laws; (4) slowness and generally unknown or uncertain response of ground-water reservoirs to development; and (5) all forms of potential contamination. Such difficulties combine to make ground water the "mixed blessing" that it is. Nevertheless, history and hydrologic realities signify clearly that we will depend on the ground-water reservoirs for a large part of our total water supply.

Geology and Ground-Water Resources

The New York State section of the Susquehanna River basin lies wholly within the Southern New York section of the Appalachian Plateaus physiographic province. This glaciated mature plateau of moderate relief receives from 32 to 42 inches of mean annual precipitation. The bedrock underlying the unconsolidated surficial deposits is composed of interbedded shale, siltstone, and sandstone of Devonian age. The beds are nearly horizontal. Although the bedrock becomes increasingly sandy toward the east, this change in grain-size appears to have little affect upon the water-bearing properties of the bedrock, which stores and transmits water in fractures. Nearly the entire area is mantled by unconsolidated surficial deposits of Pleistocene and Holocene age. The uplands and minor valleys are predominantly covered by a thin veneer of silty, sandy till. The major flat-bottomed valleys contain a thickness of from 100 to 500 feet of glacial ice-contact material, glacial lacustrine deposits, and glacial outwash. Fine-grained lacustrine deposits are predominant in much of the upper reaches of the Susquehanna River valley and its tributaries above Binghamton and in the Canisteo River valley; however, more than 10 feet of sand and gravel outwash occurs throughout 85 percent of the area containing major flat-bottomed valleys, as delimited in figure 5. These areas include: the Cohocton River valley between Cohocton and Corning, at least four-fifths of the Chemung River valley between Corning and Waverly, at least four-fifths of the Susquehanna River valley between Kirkwood and Waverly, at least two-thirds of the reaches of the Chenango and Tioughnioga Rivers, and at least half of the reaches of the Susquehanna River above Susquehanna, Pa.

Wells in Pleistocene sand and gravel are potentially 30 times more productive than wells in the Devonian bedrock. Yields from properly constructed wells in sand and gravel can average about 2,000 gpm (gallons per minute) whereas yields from wells in the bedrock can average only about 60 gpm. Costs of developing ground water range from an average of 5 cents per thousand gallons from the bedrock to an average of less than a cent per thousand gallons from the sand and gravel. Water from the unconsolidated deposits tends to be considerably harder than water from the bedrock. Objectionable amounts of iron may be encountered in either. Deep wells in the bedrock often produce hydrogen sulfide, natural gas, and occasionally large concentrations of salt.

In general, abundant low-cost ground water of generally satisfactory quality is available from sand and gravel in nearly all the major valley areas of the Susquehanna River basin in New York State.

Ground Water Problems

The New York section of the Susquehanna River basin is situated within an area having a humid continental climate and has no present or foreseeable overall shortage of water. Local shortages are commonly the result of uneven distribution of supply and inadequate water-development facilities rather than an inadequate total resource. Other water problems are numerous but generally are not as critical as they are in many other parts of the United States. The following four problems are deemed most significant in the New York section of the basin: (1) determining the local availability of water, (2) regulating the use of water and spacing of development facilities to prevent overdevelopment, (3) treating or avoiding water of a natural quality unsuitable for some uses, and (4) protecting the water from contamination.

Availability of Supply

Locating ground-water supplies is a problem in many places in the New York section of the basin because of a lack of specific knowledge on the occurrence of water in fractures in the bedrock and because of the heterogeneity of the unconsolidated deposits. The problem of loacting adequate ground-water supplies from bedrock will become more acute as suburban, domestic expansion in the larger metropolitan areas shifts its focus from the valleys onto the valley slopes and uplands. Research in progress on the association of ground water with fracture traces appears to hold promise toward mitigating this problem. As municipal and industrial demands for water steadily increase in the valley areas, it will be necessary to explore more thoroughly for the most productive zones in the unconsolidated deposits, especially by test drilling. Though it is possible to generalize about ground-water conditions regionally, it rarely is possible to predict quantity, cost, and quality within narrow limits without prior exploratory test drilling. Investigations are continuing in the New York section of the basin to better define the history, variability, and hydrology of the unconsolidated deposits.

Overdevelopment

In general, the ground-water resources appear to be ample to meet future needs, and the problems of overdevelopment that may arise are those of distribution of the supply and spacing of development facilities to make use of the total resource. The large metropolitan centers of Binghamton, Corning, Cortland, and Elmira, are areas of potential overdevelopment. The day when fresh water will have to be reused many times in these areas may be delayed by locating new wells next to rivers, to capture natural ground-water discharge, and by spacing wells far enough apart to reduce their mutual interference.

Domestic, municipal, and industrial users have been generally successful in obtaining all the water they need at a cost within their ability to pay. This does not mean that there have not been individual hardship cases. Some industries have unfortunately located well fields with closely spaced wells far away from areas of natural ground-water discharge, resulting in increased pumping costs due to deep pumping levels. In addition, in any area the size of the New York State section of the basin, there are places where the ground-water resources are so inadequate that even small communities or suburban subdivisions could experience overdevelopment problems. In general, however, the ground-water supplies have met the demands placed upon them.

Unsuitable Natural Quality

The natural quality of ground water is a problem to some water users. Five out of 54 samples of water from bedrock contain chloride in concentrations exceeding the limit recommended by the U. S. Public Health Service for drinking water (250 mg/l); 20 out of 45 samples from bedrock contain iron in concentrations exceeding the limit recommended for drinking water (0.3 mg/l). It should be noted, however, that water may be treated for iron removal at a cost that most homeowners are able to pay.

Water from unconsolidated deposits in the major valleys commonly contains iron in objectionable concentrations. Seventy-four out of 340 samples contain iron in concentrations exceeding the limit recommended for drinking water. Water from the unconsolidated deposits also is very hard. Four hundred and eight samples average 182 mg/l (milligrams per liter), 40 samples exceed 280 mg/l, and 100 samples exceed 225 mg/l. Some industries find it necessary to soften ground water or use an alternative source of supply.

Contamination

In an area where the total water resources are adequate to meet foreseeable demands, contamination poses the most serious threat to water supplies by diminishing the total usable resource. The usable fresh water supply may be diminished by introducing contaminants either in concentrated form or in dilute form as inadequately treated waste water. In addition, large withdrawals of fresh water may induce flow of natural water of inferior quality into a fresh-water reservoir.

Ground-water contamination is significantly different from surface-water contamination in two respects. Contaminants in ground water move more slowly and are subject to less dispersion and dilution than those in surface water. Normal surface-water flow rates are about 5 feet per second while normal ground-water flow rates are between about 5 feet per day and 5 feet per year. The slower movement of contaminants in ground water results in longer lasting effects at a point of ground-water withdrawal. Effects may first appear at some point of withdrawal years after contamination began, and obviously elimination of the contamination at its source will not result in the reduction of contamination at the point of withdrawal until a similar period of time has elapsed. Surface-water flow is normally turbulent and tends to disperse and dilute contaminants. Ground-water flow, on the other hand, is almost always laminar and tends to move contaminants down-gradient in essentially the same concentrations at which the contaminants were introduced into the ground-water flow system.

Contaminants can be introduced from the ground surface in many ways. Contaminants may be injected through wells either unintentionally (as when home-heating fuel oil was pumped into a driven well mistaken for a fuel tank supply line) or intentionally (as when ponded, stagnent surface water was drained into dry wells). Contaminants may leak from inadequate tile fields, broken sewers, industrial waste settling basins and disposal ponds, or deteriorated underground storage tanks. Contaminants in concentrated form may be leached from surface storage piles, such as stockpiles of salt for highway snow removal, or from uncovered sanitary land fill. Contaminated surface water may be induced to flow into well fields adjacent to rivers.

Contaminants are most commonly introduced into an aquifer from the surface. However, where two or more aquifers containing water of varying quality are in hydraulic continuity, water of inferior quality may be drawn into the aquifer from which fresh water is being withdrawn. Where aquifers having different quality are not in hydraulic continuity, either multiple-screened or deteriorating wells may provide avenues for flow of water from one aquifer to the other.

Fine-grained lacustrine sediments comprise the majority of the geologic section in some areas, but they are not necessarily at the top of the section. In extensive areas of the major valleys in the Susquehanna River basin in New York State, very permeable sand and gravel are exposed at the surface and extend downward to the principal ground-water reservoirs, rendering these reservoirs highly susceptible to contamination from the surface. Solid matter is filtered out and some contaminants are adsorbed by interspersed fine-grained material, but the remaining contaminants inevitably percolate to the ground-water reservoir and are carried to areas of discharge at wells, springs, lakes, and streams.

At least five wells on record, completed near the bottom of the unconsolidated deposits in the major valleys, yielded water of good quality during their early pumping history but yielded water of relatively poor quality later in their history, as evidenced by increases in dissolved solids--particularly chloride. This change in quality suggested that water had been induced to flow out of adjacent aquifers containing water poorer in quality than the water in the aquifer in which the wells were completed.

Population growth and industrial expansion have combined to produce an increasing quantity and variety of contaminants. In recent decades, population growth has centered in suburban developments where septic tanks are the most common means of domestic sewage disposal. Industries also have been moving to the periphery of large metropolitan centers and establishing individual waste-disposal systems. This decentralization of points of waste disposal has vastly increased the area that may be affected by contamination under certain conditions.

METHOD OF ANALYSIS

Data Available

This appraisal of ground-water resources is based upon available geologic and hydrologic data. Exposures of unconsolidated deposits in the major valleys have been examined and mapped. In addition, a well inventory provided 900 well schedules containing physical, hydrologic, and geologic data--including geologic logs of the materials penetrated.

Specific-capacity data for about 260 wells and aquifer-test data for 20 wells were used for appraising the quantity of water that may be obtained from wells. Current price schedules for drilling and equipping wells and for electric power use were used for appraising the cost of developing ground water. Records of 360 chemical analyses of well water were used for appraising the quality of water from wells. Of these analyses, 66 percent were collected and analyzed by the New York State Department of Health, 21 percent by private laboratories, and 13 percent by the U. S. Geological Survey.

General Method

A technical summary of the method of analysis is presented in the following paragraph. A more general discussion of the details and assumptions involved in applying the method is presented under sections entitled "Quantity Analysis," "Cost Analysis," and "Quality Analysis."

Reported specific capacities for wells tapping each aquifer were adjusted to theoretical 180-day values, arranged in order of magnitude, and plotted on log-normal probability paper. Straight lines were fitted to all the plots. Estimated well yields and costs to develop ground water from each aquifer were obtained for the 25, 50, and 75 percent probabilities of occurrence of the specific capacities for successful wells. The estimated well yields at these probabilities of occurrence were obtained using hypothetical well designs and selected drawdowns based upon the physical properties of each aquifer. Ground-water costs for the design yields were calculated using amortized costs of well construction, electrical power costs, and maintenance costs, all obtained from standard sources. Estimated chemical quality of ground water from each aquifer was obtained for the 25, 50, and 75 percent probability of occurrence of the concentrations of chemical constituents in analyzed samples of well water.

Quantity Analysis

Theoretical considerations

Accurate estimates of the quantity of ground water available to wells over a long period in any water-development area must be based upon both the safe yield of aquifers and the hydraulic properties of aquifers. If estimates of quantity are based solely upon the hydraulic properties of aquifers, as they are in this report, it must be assumed that the rate of ground-water withdrawal will not exceed the safe yield for the area.

Safe yield may be defined as the rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible. An accurate appraisal of the safe yield for an area involves a costly study extending over several years to determine the following: (1) rates at which water enters the area from all sources, (2) rates at which water leaves the area from all points of discharge, and (3) modifications of these rates resulting from activities of man. In addition, for the accuracy of such an appraisal of safe yield to remain valid over a long period of time, any changes in technology, changes in areal distribution of water use and re-use, and changes in economic base that might permit more costly methods of increasing safe yield would have to be accurately predicted. Such a study is beyond the scope of the present investigation. Experience to date indicates that ground-water withdrawals are apparently exceeding safe yield in only a few small areas of densely spaced wells. Using consulting engineers, consulting geologists, and well contractors to locate future wells should reduce the danger of the safe yield being exceeded. It is, therefore, assumed that all the water required in an area can be obtained from ground-water sources--if not from nearby wells, then from more distant wells--and that the only limitation is the cost of the water.

The hydraulic properties of an aquifer upon which estimates of quantity of available water may be based are those properties determining the ability of the aquifer to store and transmit water. These hydraulic properties may be estimated from the following types of data, listed in order of increasing reliability: (1) reported well yields, (2) specific capacities, and (3) quantitative aquifer tests.

Reported values of well yields often depend as much upon effort made to obtain water for a specific purpose (and corresponding well design) as upon the hydraulic properties of the aquifer. For instance, larger well diameter, greater well depth, greater pump capacity, greater drawdown, or additional well development may all result in increased yield. When an attempt is made to appraise the water-bearing characteristics of an aquifer using reported well yields only, all these variables affect the results of the appraisal. The results of the appraisal, therefore, may be more a function of well design and effort to obtain water than a function of the water-bearing characteristics of the aquifer. Well yield data, especially data containing a large percentage of records from small domestic wells, are an inaccurate measure of the hydraulic properties of aquifers and corresponding quantity of water available.

Quantitative aquifer tests attempt to measure the hydraulic properties of aquifers while taking into account some of the variables in well design and effort to obtain water. Considerable cost in time, materials, and personnel is involved in conducting reliable aquifer tests, and as a result, basin-wide aquifer-test data are rarely available. In the absence of abundant aquifer-test data, specific-capacity data provide a basis for comparing wells of different yields and estimating the hydraulic properties of aquifers.

The specific capacity of a well is defined as the yield of the well per unit of drawdown of the water level. Thus, a well yielding 100 gpm with a drawdown of 5 feet has a specific capacity of 20 gpm per foot of drawdown. Conversely, the use of specific-capacity data allows the computation of potential well yields from an aquifer for any well design if the value of available drawdown is known. By using the median value of specific capacity for wells in an aquifer, a reasonable estimate of potential well yields is obtainable.

The theoretical specific capacity of a well discharging at a constant rate in a homogeneous, isotropic, non-leaky artesian aquifer, infinite in areal extent, is taken from the Theis equation modified in the following equation (Walton, 1962, p. 12):

$$\frac{Q}{s} = \frac{T}{264 \log \left(\frac{Tt}{2693 \, r_w^2 \, S} \right) - 65.5} \qquad (1)$$

where:

$\frac{Q}{s}$ = specific capacity, in gallons per minute per foot of drawdown

Q = discharge, in gallons per minute

s = drawdown, in feet

T = coefficient of transmissibility, in gallons per day per foot

S = coefficient of storage, unitless

r_w = nominal radius of well, in feet

t = time of measurement after pumping started, in minutes

Hence, the specific capacity of any individual well is dependent upon the following: the transmissibility of the aquifer, the storage coefficient of the aquifer, the pumping period, well losses, effective well radius, the effects of partial penetration, and geohydrologic boundaries. Transmissibility is the only variable in the equation that--in part--is directly proportional to specific capacity. Therefore, high specific capacities generally indicate that an aquifer is capable of transmitting large quantities of water, and low specific capacities generally indicate an aquifer is capable of transmitting only small quantities of water. The specific capacities of wells in an aquifer may, however, differ greatly from place to place depending upon all the above factors. Therefore, it is impossible to predict with a high degree of accuracy the yield of a well at any specific loation before drilling. In fact, it might be possible to drill what is essentially a dry hole at almost any location in the basin. However, statistical analysis of specific capacities can be a great help in appraising the relative role of individual aquifers as producers of water. Assuming that hydraulic conditions encountered in the future will be similar to conditions encountered in the past, the probable range of specific capacities of future wells can be estimated based on frequency graphs of reported specific capacities. Specific-capacity data were available for wells penetrating each of the aquifers analyzed in this report, and these data were used to estimate the range and the relative consistency of well yields tapping each aquifer.

Specific-capacity frequency

Specific capacities for wells in each aquifer were tabulated in order of magnitude, and their frequencies were computed with the following equation (Kimball, 1946):

$$F = \frac{m_o}{(n_w + 1)} \quad 100 \qquad (2)$$

where:

m_o = the order number

n_w = total number of wells

F = percentage of wells whose specific capacities are equal to, or greater than, the specific capacity of order number m_o.

Specific capacities were then plotted against percentage of occurrence on logarithmic-probability paper. (See figure 2 as an example of such a plot.) Straight lines were fitted to the data. The slope of the specific-capacity frequency graph varies as the range in specific capacity varies. A steeper line indicates a greater range in well yield per foot of drawdown.

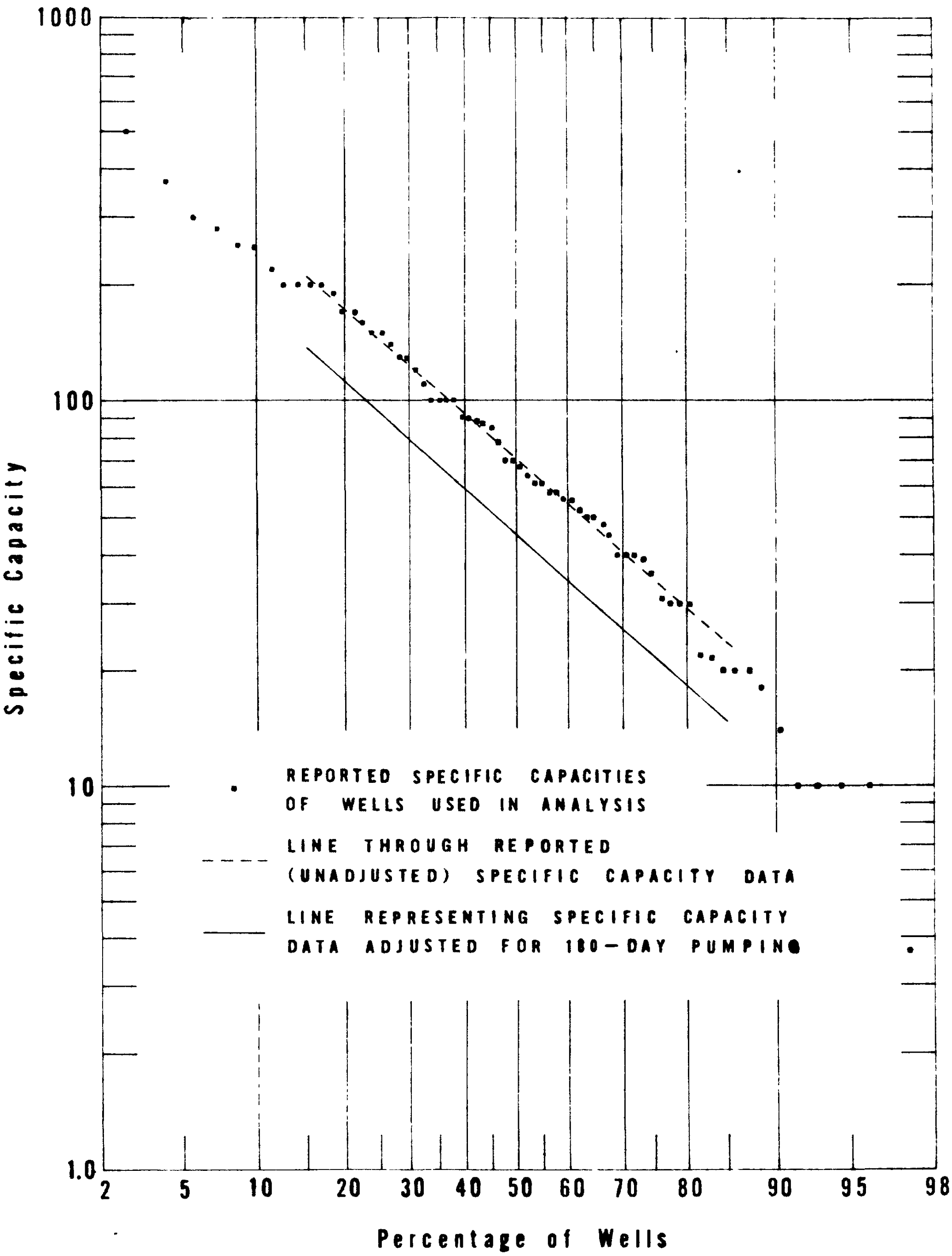

Figure 2.--Specific-capacity frequency-distribution graph for Pleistocene outwash less than 50 feet deep and between 10 and 40 feet thick.

As can be seen in equation (1), specific capacities theoretically decrease as time increases during periods of continuous pumping. Specific capacities used in this analysis were obtained at various pumping rates and for various periods of continuous pumping, mainly of short duration. One of the objectives of the study was to compute a sustained yield for each well. Hence, all the specific-capacity data were adjusted to a conservative, common pumping period using graphs given in Walton, 1963, p. 12-13. The figure used was 180 days, which is probably the longest period in which no recharge would occur. In general, this cut the reported specific capacities (which were generally obtained after one hour or one day of pumping) to less than two-thirds their original value. The decline in theoretical specific capacity from 180 to 365 days is very small. A specific capacity based on 180 days of pumping probably represents a good approximation for a well pumped 24-hours a day for 365 days a year. In practice, the well would most likely be pumped only 12 hours a day and allowed to recover for 12 hours. The 180-day specific-capacity figure used reflects 24-hours a day pumping and allows a realistic yearly pumping figure to be computed without an unjustified refinement of the computations.

The coefficient of storage, S in equation (1), can usually be estimated from well-log and water-level data. Because specific capacity varies with the logarithm of $\frac{1}{S}$, large errors in estimating coefficients of storage result in comparatively small errors in specific-capacity data adjusted to a common time base. Hence, a coefficient of storage of 0.2, which is a common water-table coefficient, was used to adjust the specific-capacity data. This is a conservative figure to use for the computations of potential well yields because it gives a greater reduction in specific capacity with time, during the period over which the specific capacity was adjusted, than would be obtained by using coefficient of storage representative of artesian conditions.

It was assumed that any well yielding less than 10 gpm (based upon time-adjusted specific capacity and available drawdown) would be considered unsuccessful by a municipality, industry, or irrigator. After the specific-capacity frequency distributions had been constructed, using all the available data, and had been adjusted for 180-day pumping, specific capacities that gave computed yields of less than 10 gpm were eliminated from the distribution. Six of the 10 aquifers analyzed had less than 10 percent of the sample thus eliminated. For only one aquifer, the lacustrine deposits, was as much as 20 percent of the sample eliminated.

The remaining specific capacities of successful wells were redistributed for those aquifers in which greater than 2 percent of the sample obtained less than 10 gpm. Specific capacities equaled or exceeded in 75 (poor), 50 (medium), and 25 (good) percent of these successful wells were picked from the new distribution graph and reported in table 1.

In order to account for bias introduced in the sample by eliminating unsuccessful wells and by using data largely collected from municipal and industrial wells, it was further assumed that exploratory wells would be drilled in each aquifer. The cost of constructing these exploratory wells is discussed in the section on initial costs and is included in the cost of wells and ground water shown in table 3.

Estimated yields of wells

The 50 percent (medium) time-adjusted specific capacity of successful wells in each aquifer multiplied by the available drawdown gives a reasonable estimate of the average potential yield than can be expected from a single well in each aquifer. The 75 percent (poor) and the 25 percent (good) time-adjusted specific capacities of wells in an aquifer multiplied by the available drawdown give the approximate range in potential yields than can be expected from 50 percent of the wells in that aquifer.

The available drawdown for each aquifer was estimated on the basis of an analysis of well records for each aquifer. Particular emphasis was placed on static water levels, depth to the aquifer, depth and distribution of the water-yielding zones in the aquifer, and depth and yield of wells encountering these zones. Based upon this analysis, the available drawdown in each aquifer in the New York State section of the basin was taken as one-half of the difference between the median static water level and the representative depth of wells in each aquifer. This value, considered to be the maximum available drawdown in each aquifer, is probably the maximum amount that the static water levels may be drawn down by pumping without seriously impairing the water-yielding properties of the well. This maximum drawdown, when multiplied by the specific capacity for each probability of occurrence (poor, medium, and good), results in yield values for each aquifer.

Even though the foregoing assumptions may have very little relationship to the actual yield of a specific well, the yields thus computed are believed to be realistic for the aquifer as a whole, and are probably conservative. This method of computing well yield, when used in conjunction with an estimate of safe yield as a limiting value, will provide a reasonable basis for estimating what long-term yields may be expected from a series of properly-spaced wells drilled in a particular aquifer.

Cost Analysis

Well design

Estimates of the cost of ground water available in any water-development area may be based upon the designs of hypothetical wells that conform to the hydraulic and physical characteristics of the aquifers they tap. For each aquifer, hypothetical wells were designed to produce the estimated potential yields, which were calculated from available drawdown and the 25, 50, and 75 percent probability of occurrence of specific capacity. Geologic, hydrologic, and well-construction data in addition to specific-capacity data were assembled and analyzed by aquifer to aid in the design of hypothetical wells.

In conformance with the physical characteristics of the aquifer as analyzed, well depths were chosen to penetrate almost all the water-yielding zones in the aquifer. A representative depth of wells in each aquifer in the basin in New York State was chosen to be that depth which equaled or exceeded the reported depths of 75 percent of existing wells in that aquifer. The 75 percent depth was chosen rather than the 50 percent or average depth to insure that the hypothetical wells penetrate the majority of producing zones.

Well diameters were chosen to accommodate the size pump needed to produce the estimated potential yield, in most cases allowing a 1-inch annular space.

Casing length for wells in the bedrock aquifer was taken as the average of reported lengths, and for wells in the unconsolidated aquifers it was taken as the representative depth of well minus the screen length. Casing diameter was taken as the diameter of the well as drilled.

Screens were used in the design of wells in unconsolidated aquifers only. Screen lengths were chosen according to the saturated thickness of the aquifers and the diameters were the same as the casing.

The pumping water levels used in the design of pumping equipment were taken as the sum of the median static water level and the available drawdown as used in the calculation of potential yields.

Deep-well turbine pumping equipment, including motor, column, shaft, pump, and strainer was designed for each hypothetical well to produce the estimated potential yields from the pumping water levels perviously determined with the smallest possible value of pump working horsepower.

Pumping equipment was designed to deliver the estimated potential yields at the land surface, under zero discharge pressure. The yields were not delivered under pressure in order to facilitate comparison with surface-water quantities and costs estimated for this condition of pressure.

Each hypothetical well was furnished land and rights-of-way, pumphouse, water meter, valves, electrical control panel, and local piping selected to conform to the design of the pumping equipment.

Cost calculations

The assumption was made that ground water is available for all needs if the user is willing to pay for the supply. This assumption is based upon the fact that all widespread aquifers will yield large quantities of water, although the yields of individual wells are generally greater from good aquifers than from poor ones. Hence, the question of whether the use of ground-water reservoirs is feasible is to a large extent a matter of the bearable cost of water.

The cost of water supply can be divided into the costs of: (1) works for collection of water, (2) works for the purification of water, and (3) works for the conveyance of water. For consistency with other estimates being made in the Susquehanna River basin study, this report will disucss only those costs related to the collection of water. The collection costs are those of construction, operation and maintenance of the hypothetical wells and they may be broken down into (1) intial costs and (2) annual costs. Estimated unit costs of ground water are based upon the relationship of annual costs to the yields for which the annual costs were calculated. The initial costs are the costs for the construction of the design well. The annual costs are those costs to operate and maintain the well, which include: (1) costs to amortize the initial cost, (2) power costs, and (3) maintenance costs.

Initial costs of the design well include: (1) drilling exploratory wells, and drilling, developing, and testing the production well; (2) equipment--including casing, screen, strainer, pump, column, shaft, motor, meter, valves, and inside piping; (3) pumphouse and electric controls; (4) land and rights of way; and (5) contingencies and engineering, including administration.

Initial costs.--Cost estimates were obtained from published reports and from industries, such as well drilling firms that install such equipment. The costs given herein are only estimated costs, which will differ from place to place and from time to time. The costs will vary according to the regional location of the well, the geohydrologic setting of the well, the well construction and methods used in well construction by the contractor, and the desire of each contractor bidding to obtain the construction contract. The costs are May 1966 prices and can be converted to approximate present prices by comparison with the Engineering News-Record Construction Cost Index, which was 1014 in May 1966 (Eng. News-Rec., vol. 176, no. 18, p. 62).

The factors considered in arriving at the initial cost of the wells are discussed below.

The depth and diameter of the hypothetical wells are discussed in the section on well design. For the bedrock aquifer, one exploratory well for every successful production well was assumed to be a reasonable average to make the specific-capacity analysis valid in predicting well yields and costs. The exploratory well in this case would have the same diameter as the successful production well. For the unconsolidated aquifers, three exploratory wells (of 6-inch diameter) for every successful production well (of specified diameter) was estimated to be a reasonable average. The exploratory wells may be used later as observation wells to determine the hydraulic properties of the aquifers in the area and for monitoring water-level fluctuations during production. The estimated unit costs of drilling wells is tabulated in the section on explanation of tables.

A total of 48 hours was deemed satisfactory for developing and pump testing the production well. The ratio of development duration to pump-test duration will vary according to characteristics of the well, aquifer, and the geohydrologic setting but should be proportioned both to adequately clean the well and to provide data for designing the deep-well turbine pumping unit. Estimated unit costs for developing and pump testing are given in the section on explanation of tables.

The specific lengths and diameters of casing and screening for the aquifers are discussed in the section on well design. The estimated cost of casing and screening is given in the section on explanation of tables.

A family of curves was developed relating the cost of deep-well turbine units to well yields for pumping water levels of 25, 50, 100, and 200 feet. (See fig. 3.) Costs of the equipment were selected from current manufacturers' price tables and were based upon potential yields and well designs.

The estimated fixed costs of land, rights-of-way, and a pumphouse--as well as unit costs for water meter, valves, local piping, and electric control pannels--are given in the section on explanation of tables. Costs of this equipment for each hypothetical well were selected from the unit costs based upon hypothetical well deaign.

Ten percent of the estimated construction and equipment costs was included for contingencies and 15 percent for engineering and administration.

In order to compare initial costs per unit yield for different aquifers at different probabilities of occurrence of specific capacity, the total initial cost was divided by the potential yield resulting in a figure of total initial cost per mgd of design yield for each aquifer at each probability of occurrence of specific capacity.

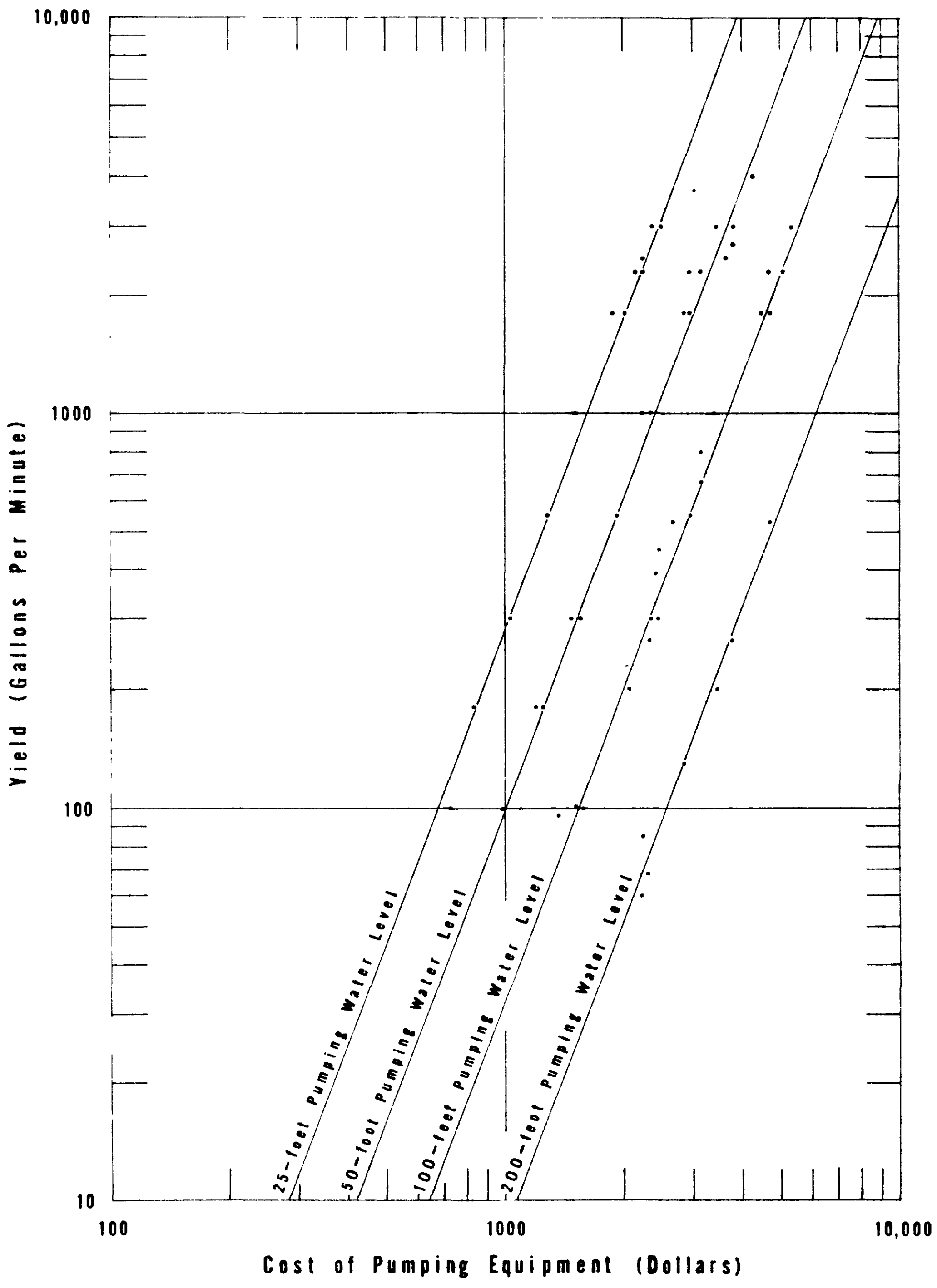

Figure 3.--Graph showing the relation of yield of hypothetical wells to cost of motor, column, shaft, pump, and strainer for selected pumping water levels.

Annual costs.--A single end-of-year payment to cover interest on the initial cost and payments to a depreciation fund may be calculated using the formula for uniform annual series of end-of-year payments. This method is referred to as the capitol-recovery-factor method of cost accounting (Grant and Ireson, 1960, p. 45):

$$R = P \frac{i\,(1 + i)^n}{(1 + i)^n - 1} \qquad (3)$$

in which

R = The end-of-period payment in a uniform series of equal payments continuing for the coming n periods

P = Total initial cost

i = Annual interest rate, taken as 4 percent on municipal bonds in this report

n = Number of interest periods, taken as 25 years in this report

$\frac{i\,(1 + i)^n}{(1 + i)^n - 1}$ = The capital recovery factor which, when multiplied by a present debt, gives the uniform end-of-year payment necessary to repay the debt in n years with interest rate i. This factor is 0.06401 where the annual interest rate is 4 percent, and the length of the period is 25 years, using a uniform series of payments.

Annual power cost used herein was based upon New York State Electric and Gas Corporation electrical power rate schedules for general service, classification 2 and 3, P.S.C. No. 109 (May 1966). Total power consumption was estimated by using the pump working horsepower of the individually designed pumping equipment from table 2, by assuming a 24-hour a day use, and by assuming 75 percent wire to motor efficiency so that 1 horsepower equals 1 kilowatt. Figure 4 was used in the estimation of annual power costs.

Annual maintenance cost was estimated from data obtained from drilling contractors and utility commissions and is here taken as 4 percent of the cost of the pumping equipment. Over a period of 25 years, which is assumed to be the life of the equipment, this equals the cost given in table 3 and amounts to replacing the deep-well turbine unit once within 25 years of assumed life of equipment.

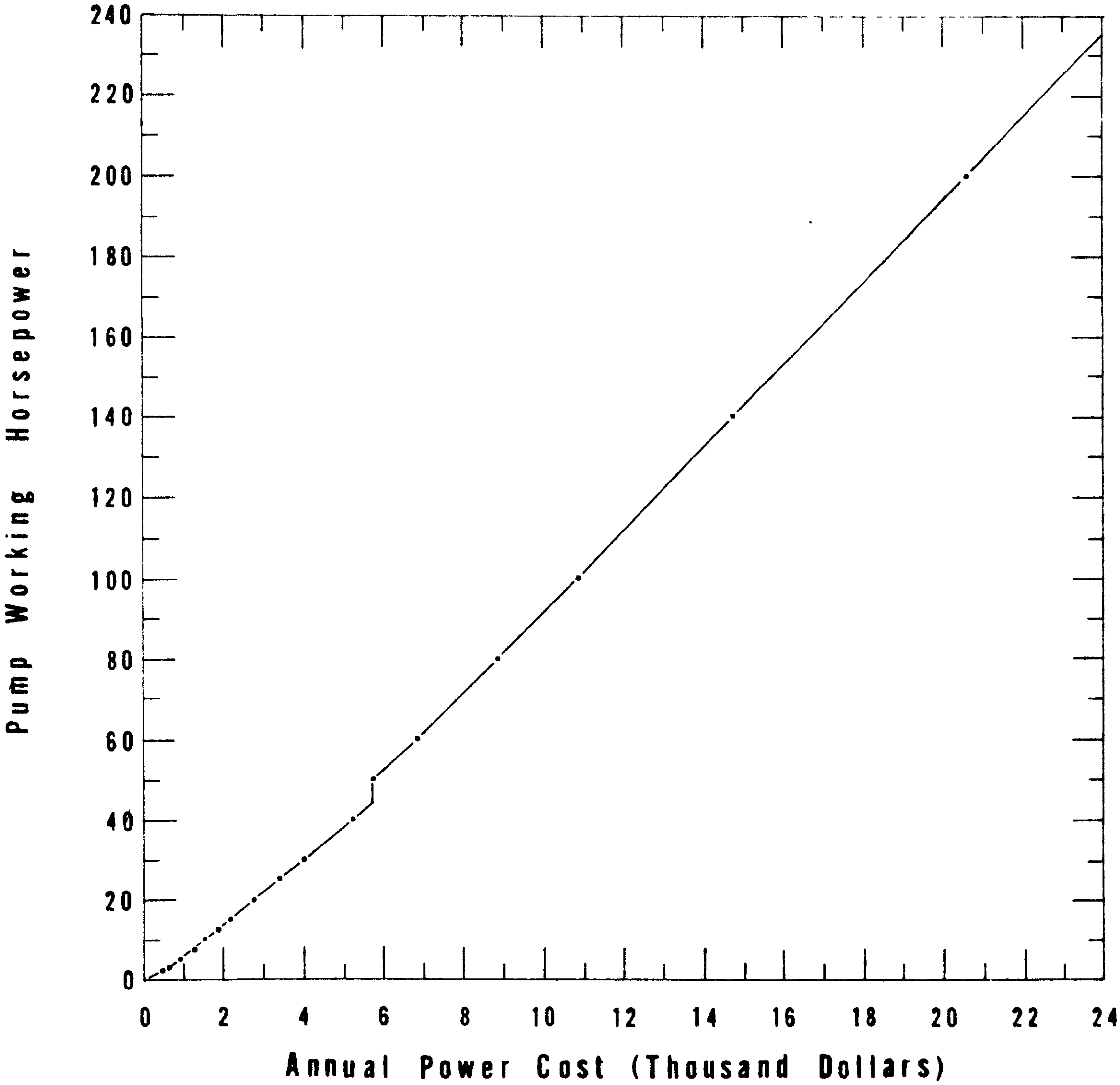

Figure 4.--Graph showing the relation of annual power cost to pump working horsepower given in table 2, assuming a power demand of 24-hours a day.

In addition to costs for replacing the pumping equipment, 4 percent of $1,500 ($60) was added to the annual maintenance cost of screened wells only. Several existing wells in the unconsolidated aquifer have a tendency to become clogged with sand during continuous use, and $1,500 is the amount estimated to redevelop these screened wells once in their assumed 25-year life.

No labor costs for operation were included. The well is assumed to be added to an existing distribution system that has supervisory personnel, and the additional labor cost would not be great.

The total annual cost is the sum of the annual payments to retire the initial cost, the annual power costs, and the annual maintenance costs. It is emphasized that this is the cost to add a well to an existing distribution system, and does not include cost of treating the water or of delivering the water to the consumer.

Ground-water costs.--Unit costs of ground water to the producer may be estimated by dividing the total annual cost per well by the potential yield of each well upon which the costs were based.

These costs are valid only for the design yield given and for a well identical in cost and construction characteristics to the hypothetical well. Obviously, the assumptions made in the well design, aquifer characteristics, probability analysis, pumping schedule, and cost analysis make this figure impossible to apply to an actual well in the field. The figures are only meant to be used as a rough guideline for a preliminary screening of potential alternate sources of water supply for the designated water-development areas. Actual site analysis of both yields and costs will have to be done by those competent in the field. However, the yields and cost figures given in this report are thought to be within the range of what can reasonably be expected at an average well site if the work in designing and constructing the well is done by competent personnel. It must be emphasized that because of the general treatment used in this report, it is not intended for use in design of specific engineering projects.

Quality Analysis

Chemical analyses of well water were assembled and analyzed by aquifer to estimate the range in quality and relative consistency in quality in each aquifer. Frequency distributions were developed for each chemical constituent and each physical property of water from each aquifer. Concentrations or values equaled or exceeded in 25 (poor), 50 (medium), and 75 (good) percent of these analyses were picked from the distributions and reported in table 4. Because the 25 percent (poor) and 75 percent (good) values give the middle 50 percent range in quality only, higher or lower concentrations may occur in water from any particular well tapping the aquifer analyzed.

Each aquifer exhibits a range in the concentration of chemical constituents in the water it contains. On the other hand, it must be emphasized that an individual well usually yields water of a quality that either is uniform throughout the year of shows a gradual progressive change.

EXPLANATION OF TABLES

This section discusses the most important details and assumptions involved in applying the method of analysis specifically to the New York State section of the Susquehanna River basin as reflected in data in the tables.

The estimated specific capacity and the yield of the hypothetical wells are summarized in table 1 in the appendix, the design of the hypothetical wells is summarized in table 2, estimates of the cost of ground water from each aquifer are summarized in table 3, and the quality of the ground water is given in table 4. A cross reference of aquifers and water-development areas is given in table 5. Only those units that could be considered as aquifers, and for which well data are available, are listed. The symbols in table 1 are the same as those in the figures. The name of the aquifer and its stratigraphic position are given on all five tables, whereas the age and symbol are given in table 1 only.

Table 1.--Estimated Specific Capacities and Yields of Hypothetical Wells

Specific Capacity Data

Specific capacities were picked from the frequency distribution (assumed to be log-normal) of all available specific capacities and were tabulated by aquifer. Prior to picking them, the distribution graphs were adjusted to what they would theoretically be both after 180 days continuous pumping and with unsuccessful wells (less than 10 gpm) eliminated from the distribution. The specific-capacities picked are those equaled or exceeded for 75 percent (poor), 50 percent (medium), and 25 percent (good) of successful wells.

The number of wells in the aquifer from which specific-capacity data was derived is an indication of the reliability to be placed upon the analysis of the specific-capacity data. The greater the number, the more reliable the results of the analysis.

Percentage of Unsuccessful Wells

The percentage of unsuccessful wells is the percentage of wells, in the data analyzed, having a time-adjusted specific capacity that would result in a yield of less than 10 gpm based on estimated maximum available drawdown. (See table 2.) This percentage is partially a reflection of the number of domestic wells used in the analysis and partially a reflection of the chance of drilling an unsuccessful well in the aquifer.

Yield Equaled or Exceeded for Indicated Percentage of Successful Wells

The yields given in gallons per minute are the potential yields for the 75 percent (poor), 50 percent (medium), and 25 percent (good) specific capacities multiplied by the maximum available drawdowns given in table 2. Three-quarters, one-half, and one-quarter of existing successful wells, respectively, should yield at these or greater rates if pumped for 180 days to the drawdowns given in table 2. These are the yields of single wells and not of well fields.

The yields given in million gallons per day are the yields in gallons per minute multiplied by 1,440 minutes per day and divided by 1 million. The yields in million gallons per day can be converted to cubic feet per second by multiplying by 1.55 cubic feet per second per million gallons per day.

The yields given in million gallons per year are the yields in million gallons per day multiplied by 365 days per year.

Table 2.--Well Design of Hypothetical Wells

Well Depth

A representative depth of wells in each aquifer was chosen to be that depth which equaled or exceeded the reported depths of 75 percent of existing wells in each aquifer as estimated from a frequency distribution of reported depths.

Well Diameter

The diameter of the well was based on the pump size, which in turn was based on the potential yield of the well. The relationship of the potential yield of the well to the well diameter and pump size necessary to produce this predetermined yield is shown in the table below:

Yield in gallons per minute	Pump size in inches	Well diameter in inches
0 - 75	4	6
75 - 200	6	8
200 - 500	8	10
500 - 1,000	10	12
1,000 - 1,700	12	14
1,700 - 2,500	14	16
2,500 - 3,500	16	18
3,500 - 5,000	18	20
5,000 - 9,000	24	30

The diameters listed in table 2 for poor, medium, and good yields are the smallest well diameters that can be used to produce, respectively, the 75 percent, 50 percent, and 25 percent potential yields listed in table 1. This assumes the most economical well construction.

Length of Casing

For wells in unconsolidated deposits, the length of casing was taken to be the representative depth of wells in each aquifer minus the screen length. For wells in bedrock, the median of reported casing lengths was used as the length of casing for the hypothetical wells.

Length of Screen

The length of screen, used in unconsolidated aquifers only, was selected by saturated thickness of the aquifer. Twenty feet of screen was installed in hypothetical wells in aquifers greater than 40 feet thick. Ten feet of screen was specified for wells in the remaining seven unconsolidated aquifers.

Static Water Level

The figure given is a median of the static water-level data available for each aquifer.

Pumping Water Level

The pumping water level in each aquifer is the sum of the median static water level and the maximum available drawdown.

Maximum Available Drawdown

The maximum available drawdown in each aquifer was taken as one-half the difference between the median static water level and the representative depth of the well in each aquifer. The drawdowns listed in table 2 were multiplied by the corresponding specific capacities (see table 1) to obtain the potential yields given in table 1.

Pump Working Horsepower

Pump working horsepower for a given hpothetical well is the actual working power, including power used in overcoming friction loss, necessary to lift the corresponding potential yield (given in table 1) from the corresponding pumping water level (given in table 2) to the land surface. Pump bowl horsepower (HP) was computed from the following formula:

$$HP = \frac{\text{Well yield (gpm)} \times \text{pump bowl head (ft)}}{\text{Pump-bowl efficiency (decimal)} \times 3{,}960 \left(\frac{\text{ft-gal/min}}{\text{HP}} \right)} \quad (4)$$

Deep-well turbine units for each hypothetical well were selected from available pump manufacturers' stock catalogues to produce the corresponding potential yields in table 1 at the smallest value of pump working horsepower and, hence, at the lowest operating cost.

Table 3.--Estimated Costs of Hypothetical Wells and Ground Water

Initial Costs

The number of exploratory wells per production well is discussed in the section on Method of Analysis. The following drilling costs are based upon cost estimates supplied by several drilling firms in the Susquehanna River basin and upon the experience of the personnel of the Water Resources Division, Harrisburg District. It should be emphasized that they are merely estimates and not what actually may be charged in any specific location or circumstance. Well depths and diameters are tabulated in table 2.

Diameter of well, in inches	6	8	10	12	14	16	18	20	30
Drilling cost, in dollars per foot	4.50	8.00	12.50	18.00	24.50	32.00	40.00	50.00	112.00

Forty-eight hours work developing and pumping a well that would need a pump equal to or less than 10 inches in diameter was estimated to cost $1,200, and the same work on a well that would need a pump greater than 10 inches in diameter was estimated to cost $2,400. These cost estimates include charges for setting-up and dismantling equipment.

Lengths of casing and screening of the same diameter as the well are given in table 2. The estimated cost of casing and screen, including installation, is given in the following table:

Diameter of well (inches)	Cost of casing in dollars per foot	Cost of 10-foot screen and fittings, in dollars	Cost of 20-foot screen and fittings in dollars
6	4.00	440	850
8	6.00	580	1,110
10	8.00	820	1,570
12	12.00	1,080	2,060
14	14.00	1,310	2,500
16	16.00	1,600	3,010
18	20.00	1,650	3,460
20	24.00	2,040	3,810
30	40.00	2,700	4,950

The cost of deep-well turbine pumping equipment necessary to produce the potential yields given in table 1, from the pumping water levels given in table 2, was estimated from the family of curves in figure 3. This is the cost of equipment to deliver water to the land surface.

The estimated cost of land and rights-of-way is $2,000 per production well. The estimated cost of a frame pumphouse is $1,500 per production well. The estimated cost of water meters is indirectly based upon yield, as given in the following table.

Limiting yield, in gpm	100	160	350	600	1,400	2,500	3,800	5,800	11,500
Water meter cost, in dollars	170	204	360	600	1,200	2,040	2,720	3,400	7,000

The estimated cost of one gate valve and one swing-check valve is indirectly based upon yield as given in the following table.

Limiting yield, in gpm	33	75	100	180	300	1,000	2,300	3,800	20,000
Cost of valves, in dollars	64	114	119	175	178	270	465	659	1,180

Twelve feet of piping was deemed sufficient for piping within the pumphouse. The unit cost of equivalent-diameter casing was used to estimate the cost of local piping.

The estimated cost of pump control panels with circuit breaker is indirectly based upon the horsepower of the pump as given in the following table:

Limiting horsepower of pump	7.5	15	30	50	100	200
Cost of control panels, in dollars	108	163	273	570	1,215	1,270

The sum of the estimated costs for land and rights-of-way, frame pumphouse, water meter, valves, local piping, and electrical control panel is given in table 3, based upon potential yields in table 1 and well designs in table 2.

Ten percent of the preceding costs was estimated as sufficient to cover contingencies during well construction.

The allowance for engineering, including contract administration and financing, has been set at 15 percent of the total construction cost, including contingencies.

The total initial cost is the construction cost of a single well, ready to discharge the corresponding potential yield given in table 1, at the land surface.

The total initial cost, in dollars per million gallons per day added to the system at the well head, is given to allow a comparison between construction costs of alternative sources of water supply. Because these figures are based upon the yields of single wells of a single probability of occurrence, they disregard both the most probable distribution of potential yields and the total number of wells involved. The total initial cost was divided by the corresponding potential yield in million gallons per day given in table 1.

Annual Costs

The annual payments to retire total initial cost are the fixed end-of-year payments necessary to repay the corresponding total initial cost in 25 years at an annual interest rate of 4 percent, using a capital-recovery factor of 0.064.

To determine the annual power cost, annual power consumption was estimated by using the pump working horsepower given in table 2, and by assuming both a 24-hour per day use and 75 percent wire-to-motor efficiency so that 1 horsepower equals 1 kilowatt. A relationship between annual power cost and pump working horsepower was developed using applicable power rate schedules of a power corporation servicing almost the entire basin in New York State (fig. 4).

Annual maintenance cost for all wells was taken as 4 percent of the cost of pumping equipment. In addition, 4 percent of $1,500 was added to the annual maintenance cost of screened wells to redevelop these wells once in their assumed 25-year life.

The total annual cost is the annual cost of initial construction, operation, and maintenance of a single hypothetical well continuously delivering water at the land surface at the corresponding potential yield given in table 1.

Estimated Unit Costs of Ground Water

This unit cost of ground water for each hypothetical well was determined by dividing the total annual cost by the corresponding total potential production in million gallons per year. (See table 1.) The resulting figure in units of dollars per million gallons was divided by 1,000 to convert to dollars per thousand gallons. This is the unit cost of water to the producer prior to treating the water and delivering it to the consumer at usable pressure.

The average annual cost per million gallons per day for each hypothetical well was determined by dividing the total annual cost by the corresponding potential yield in million gallons per day. (See table 1.) The resulting figure is the average yearly cost to the producer to add each million gallons per day of capacity to his water-supply system.

These unit costs of ground water are valid only for the potential yields and hypothetical well designs given. They are not valid for a specific site or situation except in the almost inconceivable instance where all actual conditions equal all the assumptions made. These costs are given only to show a probable range in expected costs from an aquifer in order to compare alternate sources of water supply, both surface and ground.

Table 4.--Quality of Ground Water

The concentrations of chemical constituents and values of physical properties of well water reported by aquifer in table 4 were picked from a frequency distribution of reported chemical analyses of water samples. Concentrations equaled or exceeded in 75, 50, and 25 percent of reported analyses correspond to the good, medium, and poor chemical characteristic category, respectively. Good, medium, and poor are terms related to the variability in the quality of water in each aquifer and are not intended to imply the suitability of the water for any specific use. Concentrations exceeding the limits for drinking water standards are footnoted in the table.

All concentrations are reported in milligrams per liter. A concentration of one milligram per liter is roughly equivalent to 8.33 pounds of substance dissolved in 1 million gallons of water.

Table 5.--Cross Reference of Aquifers and Water-Development Areas

Table 5. provides a cross-reference between designated water-development areas and the aquifers available to each. The areas are listed in table 5 by counties in alphabetical order and are shown on figure 1. The aquifers listed as available occur either inside or within 1 mile of the boundaries of the areas, as lettered in table 5.

GEOLOGY

Geologic History

The rocks in the Susquehanna River basin in New York State may be divided into two principal types: (1) consolidated bedrock and (3) unconsolidated deposits.

The bedrock was originally deposited as sand, silt, and mud during the Devonian Period in geologic history by rivers draining a highland in eastern New York State. These materials were subsequently buried and altered to consolidated sandstone, siltstone, and shale. After the formation of these rocks, the entire area was uplifted and tipped gently to the south. The resulting highland was dissected by streams, producing a mature plateau of moderate relief prior to the advance of Pleistocene glaciers.

The unconsolidated deposits covering the bedrock were formed as a result of glacial ice entering the area from the north and northeast. During the Pleistocene Epoch of the Quaternary Period, ice covered the area to a thickness of several thousand feet, being thickest over valleys and thinnest over the top of the plateau. As a result of glacial erosion, some of the major previously existing valleys were deepened and widened. Owing to damming by the ice, the direction of drainage of some streams was diverted into new-formed channels or even reversed in the old valleys. The great weight of the ice depressed the earth's crust regionally without significantly modifying the relief of the area, thereby allowing segments of south-draining streams to drain northward to the ice margin where, as a consequence, lakes formed.

As the ice advanced, it picked up the local fine-grained soil, loose rock material, and pieces of bedrock. When the ice melted, these materials were redeposited in the area together with rock materials brought down from Canada, northeastern New York, and the eastern Great Lakes region. Till deposited underneath the ice was left compact and unsorted by running water. Materials that slumped off the edge of the ice, together with debris washed out of the ice and deposited near the ice margin, were often overriden by the ice and left almost as compact as till.

The ice margin eventually receded from northeastern Pennsylvania when the rate of melting exceeded the rate of movement of ice from the north. The margin receded first in the uplands, where the ice was thinner, leaving previously deposited till and later deposited ground moraine separating occasional patches of sorted coarse sand and gravel. In the valleys, debris slumped from stagnant blocks of ice and debris washed out of the melting ice were deposited adjacent to the margin of the glacier, forming ice-contact deposits and discontinuous moraines. Lakes formed intermittently in the major valleys that were dammed to the north by the ice margin. Rivers of water from the melting ice dumped their loads of rock debris into these lakes, building well sorted, stratified, deltaic deposits. The outwash deposited by the meltwater was typically coarse gravel and sand next to the ice margin, grading away from the ice margin into layered lacustrine silts and clays in the deeper parts of the lakes. As the meltwater rivers filled the glacial lakes with outwash, coarse sand and gravel was spread further down valley from the ice margin. Irregular damming of the major valleys with ice in many cases caused the meltwater to seek new outlets over the plateau along previously minor tributary valleys. Some of these meltwater channels were partly backfilled with very coarse outwash gravel, others were left bare to bedrock.

Recent rivers, having a much smaller flow than the Pleistocene meltwater rivers, have done very little in modifying and reworking the unconsolidated deposits.

Bedrock

The bedrock underlying the entire Susquehanna River basin in New York State to a depth of 400 feet is predominantly shale with thin interbeds of flaggy siltstone and sandstone. Toward the east and southeast parts of the basin, the sandstone content of the bedrock increases. The bedrock contains only one limestone formation, the Tully Limestone. This formation crops out in the northeastern part of the basin but is not of sufficient thickness or areal extent to have a significant affect on the total ground-water resources. The bedrock dips south about 40 feet per mile. Low folds with east-west axes are superimposed on the regional dip. Two sets of vertical fractures cut the bedrock, one set is parallel and one set is perpendicular to the fold axes. Fractures and bedding planes comprise a small part of the total rock volume and provide the only significant void spaces in which water can be stored and transmitted in the bedrock.

Unconsolidated Deposits

Excep for areally insignificant bedrock exposures, the entire area is mantled with unconsolidated deposits. As may be inferred from the section on geologic history, the unconsolidated deposits have a continuous textural gradation from compact, unsorted, unstratified till through variously compact, poorly-sorted, poorly-stratified ice-contact and morainal deposits to loose, well-sorted, stratified outwash. In addition, well-sorted outwash commonly grades both vertically and laterally from coarse sand and gravel (deposited by rivers) through sand and gravel (deposited in deltas) to silt and clay (deposited in lakes).

Till mantles the uplands in the basin to an average depth of 60 feet. It is composed predominantly of clay, silt, and sand derived from the local bedrock and contains larger, angular fragments of bedrock within the finer-grained matrix. Some patches of sand and gravel outwash are sparsely distributed in the till of the uplands. In deep wells in the major valleys, till can sometimes be identified overlying bedrock. Being poorly sorted, till rarely has enough interconnected void space between its particles to transmit significant quantities of water. The void spaces are numerous enough, however, to provide storage for water that recharges the underlying bedrock.

Ice-contact and morainal deposits are distributed irregularly along the sides and flats of the major valleys wherever the ice margin remained stationary. The most areally extensive occurrences of these deposits are, in general, at the junction of major tributary valleys with the major river valleys and in the major valleys along the northern boundary of the basin. These deposits are composed of small lenses and pods of coarse sediments that may be either well sorted or very poorly sorted, very compact or quite loose. Where stratification is present, the bedding often indicates that the sediments were deformed shortly after deposition. The deposits are generally heterogeneous, therefore, the volume of interconnected void space ranges widely from place to place. Though lenses of coarse, loosely packed sediment are numerous, they are small in volume and poorly interconnected.

Deposits of stratified lacustrine clay and silt occur nearly everywhere in the major valleys in the basin. In some areas nearly the entire section is comprised of these fine-grained deposits, particularly in those valleys that drained northward prior to the advance of the ice. These deposits commonly occur in the middle of the unconsolidated stratigraphic section in the valleys, separating older from younger outwash deposits. They commonly grade laterally into coarser grained deltaic deposits near major valley tributaries and into ice-contact deposits along the sides of the valleys. Though well-sorted, these deposits are so fine grained that the interconnected void spaces are too small to transmit large quantities of water.

Stratified sand and gravel outwash occurs nearly everywhere in the major valleys in the basin, but it rarely comprises the entire unconsolidated stratigraphic section. In some areas, it is less than 10 feet thick in a section containing 200 to 400 feet of unconsolidated deposits (predominantly lacustrine silt and clay). The most extensive known deposits of outwash greater than 40 feet thick are in a deep channel in the Binghamton-Endicott area. The most commonly occurring thicknesses of the outwash deposits are between 10 and 40 feet. Partly because of the predominance of shallow drilling, the majority of known outwash deposits are less than 50 feet deep. Evidence from deep drilling, however, indicates that sand and gravel outwash occurs at both the top and the bottom of the unconsolidated section. Though the outwash grades in texture from boulder gravel and sand to sand and minor amounts of fine gravel, all the outwash contains a significant proportion of rounded gravel-size material. Sorting of the particles is generally good, providing a relatively large volume of interconnected pore spaces for the storage and transmission of water. Though little is known about outwash occurring at the bottom of the unconsolidated section, it appears to be more compact and less well-sorted than outwash at the top of the section.

The unconsolidated deposits were derived predominantly from the local sandstone, siltstone, and shale bedrock. They contain a variable admixture, however, of exotic materials carried into the basin from the north by the ice. This exotic material is comprised of limestone, dolomite, sandstone, and igneous and metamorphic rocks. Limestone and dolomite material in the outwash increases the calcium-magnesium hardness of the contained water. Based upon analyses of well water, the exotic material apparently is concentrated in coarse-grained deposits in the upper part of the unconsolidated stratigraphic section.

APPRAISAL OF GROUND-WATER RESOURCES BY AQUIFER

An aquifer may be defined as a mappable geologic unit, group of units, or part of a unit that is capable of yielding usable quantities of ground water. The aquifers listed in the tables and discussed in this section are available to the designated water-development areas shown in figure 1; that is, they either underlie or are within 1 mile of the political boundaries of each area. In addition, the following appraisal by aquifer allows an evaluation of ground-water resources in other areas where the same aquifers are present.

The areal distribution of the most productive aquifer at any location in the basin is shown in figure 5 (in pocket). Although two or more aquifers may occur in the section at any one location, only the most productive aquifer is shown in figure 5. Symbols shown within the aquifer designation boxes, under "Explanation" in figure 5, refer to the aquifer identification symbols in table 1.

Data on yields, design of hypothetical wells, costs, and quality of water in each aquifer are given in tables 1, 2, 3, and 4, respectively. Table 5 gives a cross reference between these aquifers and the water-development areas to which they are available.

The following items are discussed under each aquifer: (1) the definition and determination of mappable boundaries of the aquifer, (2) water-development areas to which the aquifer is available, and (3) relative value of the aquifer as to yield, cost, and chemical quality.

Bedrock (Db)

Till directly overlies bedrock in most places in the uplands and in many parts of the major valleys. Till and bedrock, therefore, act essentially as one hydrologic unit and are both included in the bedrock aquifer. Most of the data from the bedrock aquifer were taken from wells in the major valleys where the wells penetrated the entire unconsolidated stratigraphic section before being completed in the bedrock. The information is, therefore, most pertinent to the valley sections of the basin.

Availability

Because the bedrock aquifer underlies the consolidated deposits throughout the basin, it is available to all water-development areas.

Quantity

Poor yield - 29 gpm
Medium yield - 60 gpm
Good yield - 130 gpm

Annual cost

For poor yield - $29,000 per mgd
For medium yield - $19,000 per mgd
For good yield - $13,000 per mgd

Quality

The water from the bedrock aquifer is generally of good quality for most purposes. The water contains a moderate amount of dissolved solids, and ranges from low to moderate in hardness and iron content. The bedrock aquifer contains saline water at depth which generally occurs below drainage level.

Morainal Deposits (Qm)

Ice-contact and morainal deposits are grouped into the morainal-deposits aquifer in the areas where a consistent extensive sand and gravel aquifer could not be identified. They are included in one of the outwash aquifers in other areas. Most of the data from the morainal-deposits aquifer were taken from wells in the major valleys along the northern boundary of the basin, and the data are most pertinent in these areas.

Availability

The morainal-deposits aquifer is available to the Binghamton, Cortland, Sidney, and Corning areas.

Quantity

Poor yield - 84 gpm
Medium yield - 260 gpm
Good yield - 840 gpm

Annual cost

For poor yield - $13,000 per mgd
For medium yield - $6,200 per mgd
For good yield - $3,800 per mgd

Quality

The water from the morainal deposits aquifer is generally of good quality for most purposes. The water contains a moderate dissolved solids content, and ranges from low to moderate in hardness and iron content.

Lacustrine Deposits

The lacustrine-deposits aquifer includes all stratified silt and clay, including "quicksand" as described in drillers' logs. Most of the hydrologic data were taken from small domestic wells, and the distribution of this aquifer was estimated from well data.

Although the distribution of the lacustrine-deposits aquifer is not shown on figure 5, these deposits are present almost everywhere in the major valleys. They are not considered to be a major source of water supply to wells in the area because of their fine-grained nature and the presence of better aquifers in all the water-development areas. They do, however, constitute a large reservoir for storage of water in conjunction with the better sand and gravel aquifers.

Availability

Lacustrine deposits are available to all the water-development areas. Thick sections of lacustrine deposits that might be a potential source of ground water occur in the Elmira, Norwich, Sidney, Oneonta, Bath, and Hornell areas.

Quantity

Poor yield - 32 gpm
Medium yield - 98 gpm
Good yield - 320 gpm

Annual cost

For poor yield - $26,000 per mgd
For medium yield - $12,000 per mgd
For good yield - $6,700 per mgd

Quality

The water from the lacustrine deposits aquifer is generally of good quality for most purposes. The water contains a low amount of dissolved solids and a moderate amount of hardness. The iron content ranges from low to high.

Outwash

All extensive deposits of relatively well sorted sand and gravel are included in the outwash aquifers. Those areas having unconsolidated deposits that might geologically be classified as ice-contact or morainal deposits, but which contain an extensive sand and gravel aquifer, are included in one of the outwash aquifers on figure 5. All the hydrologic data from the outwash aquifers were taken from wells in the major valleys--predominantly in areas of large population density, where ground-water development has been most intense. The most abundant data are for outwash aquifers greater than 10 feet thick and less than 200 feet to the top of the aquifer.

The outwash aquifers discussed in this section were subdivided according to the depth in feet to the top of the aquifer below the top of the water table and not the depth of the aquifer below land surface, and according to saturated thickness. The water table generally occurs 10 to 20 feet below land surface in the valleys. However, along the sides of the valley, in the Kame Terraces for instance, the depth to the top of the water table is much greater. This subdivision is not intended to imply that the outwash deposits fit neatly into these categories or that a continuous body of outwash is either uniform in depth below the water table or uniform in saturated thickness throughout its areal extent. The subdivision was chosen to facilitate the design of hypothetical wells and the estimation of costs.

The water from the outwash deposits is generally of good to excellent quality for most uses. However, the quality of the water, which depends greatly upon the character of the glacial material in the aquifer, differs considerably from place to place throughout the area, and may differ considerably within relatively short distances. If influenced by river recharge, the water quality may vary seasonally.

Generally, the water in the outwash deposits contains low to moderate amounts of dissolved solids and hardness. Moderate to high amounts of hardness occur in areas where the glacial drift includes large amount of limestone pebbles. The iron content ranges from low to high and differs considerably within short distances. High concentrations of chloride are found in some of the sand and gravel aquifers, particularly in the deeper deposits near the valley walls. The high amounts of chloride appear to be related to the chloride content of the Devonian bedrock underlying the unconsolidated deposits.

Shallow (< 50 feet)

Outwash aquifers at depths less than 50 feet potentially have greater sustained yield during continuous, long-term ground-water withdrawal than outwash aquifers at greater depth. In many places the shallow outwash aquifers are in hydraulic contact with surface streams in the major valleys. In such places, a significantly large percentage of water withdrawn from wells may be derived from the flow of the surface streams. As a result, pumping water levels will remain shallow, reducing the initial construction cost of wells and annual cost of ground water. The quality of water, however, will have a pronounced seasonal fluctuation because of the seasonal changes in water quality in the nearby streams.

Thin (< 10 feet), (Q_1)

The outwash aquifer that is less than 50 feet deep and less than 10 feet thick may include some sand and gravel reworked and redeposited by recent streams. Relatively few hydrologic data are available from this aquifer.

Availability

This shallow, thin outwash aquifer is available in the Binghamton, Elmira, Cortland, Hamilton, Hornell, Owego, and Sayre-Waverly areas.

Quantity

Poor yield - 66 gpm
Medium yield - 180 gpm
Good yield - 500 gpm

Annual cost

For poor yield - $8,400 per mgd
For medium yield - $4,200 per mgd
For good yield - $2,400 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The water contains a moderate amount of dissolved solids, and ranges from low to moderate in hardness and iron content.

Intermediate thickness (10 to 40 feet), (Q_2)

The outwash aquifer that is less than 50 feet deep and between 10 and 40 feet thick is the most widespread outwash aquifer in the basin. Many hydrologic data are available from this aquifer.

Availability

This aquifer is available in the Binghamton, Elmira, Norwich, Cortland, Sidney, Oneonta, Corning, Hornell, Owego, and Sayre-Waverly areas.

Quantity

Poor yield - 550 gpm
Medium yield - 1,100 gpm
Good yield - 2,400 gpm

Annual cost

For poor yield $2,700 per mgd
For medium yield - $2,000 per mgd
For good yield - $1,500 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The water contains a moderate amount of dissolved solids and hardness. The iron content is low.

Thick (>40 feet), (Q_3)

The outwash aquifer that is less than 50 feet deep and greater than 40 feet thick, in some areas contains a deep, continuous outwash channel cut into underlying lacustrine deposits; in other areas it contains thick deltaic deposits. This is potentially the most productive aquifer in the basin.

Availability

This shallow, thick outwash aquifer is available in the Binghamton, Elmira, Oneonta, Bath, Corning, Hornell, and Owego areas.

Quantity

Poor yield - 1,500 gpm
Medium yield - 3,700 gpm
Good yield - 9,000 gpm

Annual cost

For poor yield - $2,500
For medium yield - $1,900
For good yield - $1,700

Quality

The water from this aquifer is of generally good quality for most uses. The water contains a moderate amount of dissolved solids and hardness. The iron content is low.

Intermediate (50 to 200 feet)

Thin (<10 feet), (Q4)

The outwash aquifer between 50 and 200 feet deep and less than 10 feet thick occurs as thin sand and gravel deposits at depth in the center of the valleys, as sand and gravel in terraces along the sides of the major valleys, and as some of the ice-contact and morainal deposits along the northern boundary of the basin. Relatively few hydrologic data are available from this aquifer.

Availability

The intermediate depth, thin outwash aquifer is available in the Binghamton, Elmira, Sidney, Oneonta, and Owego areas.

Quantity

Poor yield - 120 gpm
Medium yield - 550 gpm
Good yield - 3,000 gpm

Annual cost

For poor yield - $8,800 per mgd
For medium yield - $4,200 per mgd
For good yield - $2,300 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The water ranges from low to moderate in dissolved solids and hardness content. The iron content ranges from low to high.

Intermediate thickness (10 to 40 feet), (Q5)

The outwash aquifer between 50 and 200 feet deep and between 10 and 40 feet thick occurs in the center of major valleys, where it is buried beneath finer-grained material, and locally in terraces on the sides of the major valleys.

Availability

This aquifer is available in the Binghamton, Elmira, Cortland, Sidney, Bath, Corning, and Hornell areas.

Quantity

Poor yield - 520 gpm
Medium yield - 1,300 gpm
Good yield - 3,300 gpm

Annual cost

For poor yield - $3,900 per mgd
For medium yield - $2,700 per mgd
For good yield - $2,000 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The water contains a moderate amount of dissolved solids and hardness. The iron content ranges from low to moderate.

Thick (>40 feet), (Q6)

The outwash aquifer between 50 and 200 feet deep and greater than 40 feet thick is believed to be largely comprised of reworked outwash but may contain a considerable admixture of ice-contact material. Most of the hydrologic data for this aquifer were taken from wells in the Binghamton-Endicott area. The concentration of data in one area may account in part for the relatively small variability in yields and costs.

Availability

The intermediate depth, thick outwash aquifer is availalbe to the Binghamton area only.

Quantity

Poor yield - 1,200 gpm
Medium yield - 1,900 gpm
Good yield 2,900 gpm

Annual cost

For poor yield - $3,800 per mgd
For medium yield - $3,100 per mgd
For good yield - $2,900 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The water contains a moderate amount of dissolved solids and hardness. The iron content is low.

Deep (>200 feet), (Q_7)

The outwash aquifer greater than 200 feet deep is largely restricted in occurrence to the thickest unconsolidated stratigraphic section in the most eastern quarter of the basin. It may contain considerable amounts of ice-contact material. There are very few data available from this aquifer. Most of the hydrologic data were taken from small domestic wells in the major valleys.

Availability

The deep outwash aquifer is available in the Norwich, Sidney, and Oneonta areas.

Quantity

Poor yield - 110 gpm
Medium yield - 600 gpm
Good yield - 3,700 gpm

Annual cost

For poor yield - $18,000 per mgd
For medium yield - $8,700 per mgd
For good yield - $5,500 per mgd

Quality

The water from this aquifer is of generally good quality for most uses. The dissolved solids content is low. The hardness content ranges from low to moderate, and the iron content from low to high.

GROUND-WATER AVAILABILITY IN WATER-DEVELOPMENT AREAS

For the purposes of this report a water-development area may be defined as a metropolitan area containing one or more political subdivisions presently serviced by centralized water-service systems. The term water-development area is considered synonymous with water-service area as employed by other agencies.

The water-development areas, shown in figure 1, were selected for the study by the U. S. Public Health Service and concurred on by the U.S. Army Corps of Engineers. They are considered to be the nucleus around which future population growth in the basin will occur. All of these water-development areas have a present population of 5,000 or more.

Table 5 gives a cross reference between these water-development areas and the best aquifers available to each. The areas are listed by counties in alphabetical order. The location in any aquifer listed as available in table 5 may be found by referring to figure 5. The aquifers listed as available occur either inside of or within 1 mile of the boundaries of the areas, as lettered in table 5. Parts of the following New York counties, not listed in table 5, lie within the basin: Allegheny, Herkimer, Livingston, Oneida, Onondaga, Ontario, Schoharie, Schuyler, Tompkins, and Yates. At this time there are no designated water-development areas in the basin within these counties.

The available aquifers in any given area may be compared and evaluated as to yield, cost, and chemical quality by referring to tables 1, 2, 3, and 4, respectively. It should be emphasized that the estimated yields and costs are based upon the hypothetical well designs given in table 2 and are applicable only if these designs are used.

SELECTED REFERENCES

The report by Leland V. Page and Paul R. Seaber (1963) entitled "Water Resources Investigations in the Susquehanna River Basin," shows the water measuring and sampling locations operated by the U.S. Geological Survey in the basin, and lists 150 selected references on water resources in the basin. A report by Paul R. Seaber (1964) entitled "Ground Water in the Susquehanna River Basin," presented at the 3rd Annual Meeting of the Susquehanna River Basin Coordinating Committee and published as Appendix H of the minutes of the meeting, contains a generalized description of the ground-water resources of the basin. These reports make it unnecessary to list a lengthy bibliography that provides a reference on the geography, geology, and hydrology of the basin.

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Table 1.--Estimated specific capacities and yields of hypothetical wells in the aquifers of the Susquehanna River basin in New York State

Specific capacity equaled or exceeded for indicated percentage of successful wells: Tabulated values are taken from a log-normal frequency distribution of reported data, adjusted for 180 days continuous pumping; 75, 50, and 25 percent are referred to as poor, medium, and good, respectively, in the text.
Percentage of unsuccessful wells: The statistical percentage of wells, in the sample analyzed, that would yield less than 10 gallons per minute based on the well design given in table 2.
Yield equaled or exceeded by indicated percentage of successful wells: Derived from specific-capacity data and well design given in table 2; 75, 50, and 25 percent are referred to as poor, medium, and good, respectively, in the text and tables 2 and 3.

				Specific-capacity data					Yield equaled or exceeded for indicated percentage of successful wells								
				Specific capacity equaled or exceeded for indicated percentage of successful wells			Number of wells used for specific capacity frequency distribution analysis	Percentage of unsuccessful wells	75 percent (poor)			50 percent (medium)			25 percent (good)		
Aquifer	Geologic age	Symbol on Figure 5	Stratigraphic position	75 percent (poor)	50 percent (medium)	25 percent (good)			Gallons per minute	Million gallons per day	Million gallons per year	Gallons per minute	Million gallons per day	Million gallons per year	Gallons per minute	Million gallons per day	Million gallons per year
Outwash	Pleistocene	Q_1	Less than 50 feet deep; less than 10 feet thick	4.4	12	33	11	4	66	0.095	35	180	0.26	95	500	0.72	260
Outwash	Pleistocene	Q_2	Less than 50 feet deep; 10 to 40 feet thick	22	45	94	70	<1	550	.79	290	1,100	1.6	580	2,400	3.5	1,300
Outwash	Pleistocene	Q_3	Less than 50 feet deep; greater than 40 feet thick	34	82	200	38	<1	1,500	2.2	800	3,700	5.3	1,900	9,000	13	4,700
Outwash	Pleistocene	Q_4	50 to 200 feet deep; less than 10 feet thick	2.3	11	60	11	8	120	.17	62	550	.79	290	3,000	4.3	1,600
Outwash	Pleistocene	Q_5	50 to 200 feet deep; 10 to 40 feet thick	13	32	82	33	<1	520	.75	270	1,300	1.9	690	3,300	4.8	1,800
Outwash	Pleistocene	Q_6	50 to 200 feet deep; greater than 40 feet thick	19	29	44	26	<1	1,200	1.7	620	1,900	2.7	990	2,900	4.2	1,500
Outwash	Pleistocene	Q_7	Greater than 200 feet deep	.67	3.5	22	9	10	110	.16	58	600	.86	310	3,700	5.3	1,900
Lacustrine deposits	Pleistocene		Entire section	.46	1.4	4.6	13	20	32	.046	17	98	.14	51	320	.46	170
Morainal deposits	Pleistocene	Q_m	Entire section	1.4	4.3	14	34	4	84	.12	44	260	.37	140	840	1.2	440
Bedrock	Devonian	D_b	Less than 400 feet deep	.22	.46	1.0	55	11	29	.042	15	60	.086	31	130	.19	69

Table 2.--Well design of hypothetical wells in the aquifers of the Susquehanna River basin in New York State

Well diameter: Chosen according to pump diameter, which is based on yields given in table 1.
Poor, medium, and good yields refer to yields of 75, 50, and 25 percent of wells, respectively, given in table 1.
Pump working horsepower: The power necessary to produce hypothetical yields given in table 1, for use in calculating electrical power costs.
water delivered to the land surface at zero pressure.

Aquifer	Strati-graphic position	Well depth (feet)	Well diameter (inches)			Length of casing (feet)	Length of screen (feet)	Static water level (feet below land surface)	Pumping water level (feet below land surface)	Maximum available Drawdown (pumping water level minus static water level) (feet)	Pump working horsepower		
			Poor yield	Medium yield	Good yield						Poor yield	Medium yield	Good yield
Outwash	Less than 50 feet deep; less than 10 feet thick	40	6	8	10	30	10	10	25	15	0.56	1.5	4.2
Outwash	Less than 50 feet deep; 10 to 40 feet thick	40	12	14	16	50	10	10	35	25	6.5	13	28
Outwash	Less than 50 feet deep; greater than 40 feet thick	100	14	20	30	80	20	10	55	45	28	69	170
Outwash	50 to 200 feet deep; less than 10 feet thick	120	8	12	18	110	10	20	70	50	2.8	13	71
Outwash	50 to 200 feet deep; 10 to 40 feet thick	100	12	14	18	90	10	20	60	40	11	26	67
Outwash	50 to 200 feet deep; greater than 40 feet thick	150	14	16	18	130	20	20	85	65	34	54	84
Outwash	Greater than 200 feet deep	350	8	12	20	340	10	20	190	170	7.0	38	240
Lacustrine deposits	Entire section	170	6	8	10	160	10	30	100	70	1.1	3.3	11
Morainal deposits	Entire section	140	8	10	12	130	10	20	80	60	2.3	7.0	23
Bedrock	Less than 400 feet deep	300	6	6	8	80	0	40	170	130	1.7	3.4	7.4

Table 3.--Estimated costs of hypothetical wells and ground water in the aquifers of the Susquehanna River basin in New York State

Yield category: Poor, medium, and good refer to yields equaled or exceeded for 75, 50, and 25 percent of successful wells, respectively, given in table 1.
Estimated costs of wells: Costs are based on well designs given in table 2 for wells producing poor, medium, and good yields given in table 1. Cost estimates obtained from several local well drilling companies.
Annual payments to retire total initial cost: Initial investment compounded at 4 percent over 25 years according to capitol-recovery-factor method of accounting.
Annual power cost: Cost estimates based on New York State Electric and Gas Corporation general service rate schedules.
Estimated costs of ground water: Average annual cost of water delivered at the well head at land surface based on yields given in table 1, well designs given in table 2, and costs given in this table.

			Estimated costs of construction, operation, and maintenance of hypothetical wells													Estimated unit costs of ground water (dollars)	
			Initial costs									Annual costs					
			Estimated costs of initial construction of wells (dollars)									Estimated costs of operation and maintenance of wells (dollars)					
Aquifer	Strati-graphic position	Yield cate-gory	Drilling wells	Develop and pump test production well	Casing, and screening production well	Motor, column, shaft, pump, and strainer	Land, pumphouse, meter, wiring, and piping	Contin-gencies (10% of sum of columns 1 thru 5)	Engineering and adminis-tration (15% of sum of columns 1 thru 6)	Total initial cost (sum of columns 1 thru 7)	Total initial cost per mgd of design yield	Annual payments to retire total initial cost	Annual power cost	Annual maintenance costs (4% of column 4 and $1,500 to redevelop screened wells)	Total annual cost (sum of columns 10 thru 12)	Average annual cost per thousand gallons of design yield	Average annual cost per mgd of design yield
	Less than 50 feet	Poor	720	1,200	560	500	4,000	710	1,200	9,000	95,000	580	140	83	800	0.023	8,400
Outwash	deep; less than 10	Medium	860	1,200	760	840	4,300	000	1,300	10,000	38,000	640	360	94	1,100	.012	4,200
	feet thick	Good	1,000	1,200	1,180	1,300	4,600	920	1,500	12,000	17,000	770	780	110	1,700	.007	2,400
	Less than 50 feet	Poor	1,900	1,200	1,700	1,600	4,700	1,100	1,800	14,000	18,000	900	1,100	120	2,100	.007	2,700
Outwash	deep; 10 to 40	Medium	2,300	2,400	2,000	2,000	5,600	1,400	2,400	18,000	11,000	1,200	1,900	140	3,200	.006	2,000
	feet thick	Good	2,700	2,400	2,400	2,800	6,600	1,700	2,800	21,000	6,000	1,300	3,700	170	5,200	.004	1,500
	Less than 50 feet	Poor	3,800	2,400	3,600	3,000	6,600	1,900	3,200	25,000	11,000	1,600	3,700	180	5,500	.007	2,900
Outwash	deep; greater than 40	Medium	6,480	2,400	5,700	4,200	8,600	2,700	4,500	35,000	6,600	2,200	7,800	230	10,000	.005	1,900
	feet thick	Good	13,000	2,400	8,200	5,900	14,000	4,400	7,200	55,000	4,200	3,500	18,000	300	22,000	.005	1,700
	50 to 200 feet deep;	Poor	2,600	1,200	1,200	1,300	4,100	1,000	1,700	13,000	76,000	830	580	110	1,500	.024	8,800
Outwash	less than 10 feet	Medium	3,800	1,200	2,400	2,400	4,800	1,500	2,400	19,000	23,000	1,200	1,900	160	3,300	.011	4,200
	thick	Good	6,400	2,400	4,100	4,500	8,500	2,600	4,500	33,000	7,700	2,100	7,800	240	10,000	.006	2,300
	50 to 200 feet deep;	Poor	3,200	1,200	2,200	2,100	4,800	1,400	2,200	17,000	23,000	1,100	1,700	140	2,900	.011	3,900
Outwash	10 to 40 feet	Medium	3,800	2,400	2,600	3,000	5,700	1,800	2,900	22,000	12,000	1,400	3,500	180	5,100	.007	2,700
	thick	Good	5,400	2,400	3,700	4,200	8,500	2,400	4,000	31,000	6,500	2,000	7,500	230	9,700	.005	2,000
	50 to 200 feet deep;	Poor	5,700	2,400	4,300	3,600	6,000	2,200	3,600	28,000	16,000	1,880	4,500	200	6,500	.010	3,800
Outwash	greater than 40	Medium	6,800	2,400	5,100	4,300	7,500	2,600	4,300	33,000	12,000	2,100	6,200	230	8,500	.009	3,100
	feet thick	Good	8,000	2,400	6,100	5,000	8,500	3,000	5,000	38,000	9,000	2,400	9,200	260	12,000	.008	2,900
	Greater than	Poor	7,500	1,200	2,600	2,600	4,100	1,800	3,000	23,000	140,000	1,500	1,200	160	2,900	.050	18,000
Outwash	200 feet	Medium	11,000	1,200	5,200	4,900	5,200	2,800	4,500	35,000	41,000	2,200	5,000	260	7,500	.024	8,700
	deep	Good	22,000	2,400	10,000	9,900	8,700	5,300	8,700	67,000	13,000	4,300	24,000	460	29,000	.015	5,500
		Poor	3,100	1,200	1,100	1,000	3,900	1,000	1,700	13,000	280,000	830	270	100	1,200	.071	26,000
Lacustrine deposits	Entire section	Medium	3,700	1,200	1,500	1,500	4,000	1,200	2,000	15,000	110,000	960	660	120	1,700	.033	12,000
		Good	4,400	1,200	2,100	2,400	4,500	1,500	2,400	19,000	41,000	1,200	1,700	160	3,100	.018	6,700
		Poor	3,000	1,200	1,400	1,300	4,000	1,100	1,800	14,000	120,000	900	500	110	1,500	.034	13,000
Morainal deposits	Entire section	Medium	3,600	1,200	1,900	2,000	4,300	1,300	2,100	16,000	43,000	1,000	1,200	140	2,300	.016	6,200
		Good	4,400	1,200	2,600	3,000	5,500	1,700	2,800	21,000	18,000	1,300	3,100	180	4,600	.010	3,800
	Less than	Poor	2,700	1,200	320	1,400	3,900	950	1,600	12,000	290,000	778	400	56	1,200	.000	29,000
Bedrock	400 feet	Medium	2,700	1,200	320	1,900	4,000	1,000	1,700	13,000	150,000	830	680	76	1,600	.052	19,000
	deep	Good	4,800	1,200	480	2,500	4,100	1,300	2,200	17,000	90,000	1,100	1,200	180	2,400	.035	13,000

Table 4.--Quality of ground water in the aquifers of the Susquehanna River basin in New York State

Values in milligrams per liter.
Chemical characteristic category: Values tabulated are taken from a frequency distribution of reported chemical analyses of well water. Good, medium, and poor refer to values equaled or exceeded for 75, 50, and 25 percent of available analyses, respectively.

Aquifer	Stratigraphic position	Chemical characteristic category	Temperature (°F)	Silica (SiO2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO3)	Sulfate (SO4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO3)	Dissolved solids (residue at 180°C)	Calcium magnesium hardness as CaCO3	Alkalinity	pH	Color
	Less than 50 feet deep;	Good	45	4.5	0.04	0.01	----	-----	----	----	150	19	8.0	----	1.6	190	97	57	7.3	----
Outwash	less than 10 feet thick	Medium	48	8.7	.11	02	48	8.5	6.0	.8	180	28	10	.07	2.6	250	180	140	7.5	5
		Poor	51	19	[a] .32	[a] .15	----	-----	----	----	250	35	20	----	7.0	340	220	190	7.6	----
	Less than 50 feet deep;	Good	47	6.8	.03	.00	45	6.0	6.6	1.1	150	25	7.8	<.05	.24	190	150	130	7.4	1
Outwash	10 to 40 feet thick	Medium	50	7.4	.06	.01	50	12	8.9	1.4	180	31	13	.1	1.0	240	200	150	7.6	2
		Poor	53	8.8	.15	.05	74	19	13	1.6	230	50	22	.2	2.1	330	220	170	7.8	5
	Less than 50 feet deep;	Good	49	6.5	.03	.01	42	6.8	4.9	.9	160	24	8.6	<.05	.1	200	160	140	7.4	1
Outwash	greater than 40 feet thick	Medium	51	8.0	.09	.02	48	13	6.0	1.2	170	32	19	.1	1.2	240	220	160	7.6	2
		Poor	52	10	.20	[a] .06	56	17	11	1.4	190	44	31	.15	3.2	390	300	210	7.7	5
	50 to 200 feet deep;	Good	50	5.1	.09	.01	18	2.4	3.0	.4	61	12	3.3	<.05	.02	100	63	37	6.5	1
Outwash	less than 10 feet thick	Medium	52	7.8	[a] .30	.05	46	7.8	6.3	.7	110	15	11	.1	.82	190	150	98	7.2	1
		Poor	54	12	[a] 1.4	[a] .15	83	20	18	1.4	210	28	16	.2	9.0	360	250	190	7.7	2
	50 to 200 feet deep;	Good	48	6.8	.03	.01	43	9.7	5.0	5	150	15	7 0	05	.12	160	120	120	7.5	2
Outwash	10 to 40 feet thick	Medium	50	9.2	.11	.05	54	14	8.0	1.1	180	19	12	.1	68	210	180	140	7 7	2
		Poor	53	10	[a] .38	[a] 24	100	19	17	1.4	210	28	24	.2	1.6	270	210	170	7.8	3
	50 to 200 feet deep;	Good	50	3.5	.05	.02	12	8.2	----	----	130	19	12	----	.09	160	140	140	7.4	----
Outwash	greater than 40 feet thick	Medium	53	4.6	.09	.05	58	12	8.1	1.2	160	27	21	.1	.5	230	210	160	7.6	3
		Poor	54	7.7	18	[a] .12	130	19	----	----	220	36	29	----	2.6	340	250	190	7.7	----
		Good	--	----	.24	----	---	----	----	----	---	----	.9	----	----	---	62	---	6.5	----
Outwash	Greater than 200 feet deep	Medium	--	7.8	[a] .60	.00	---	4.1	6.3	3	76	13	2.0	<.05	.05	89	72	62	7.4	2
		Poor	--	----	[a] 5.6	----	---	----	----	----	---	----	3.3	----	----	---	120	---	7.9	----
		Good	50	2.0	.21	----	---	----	----	----	---	----	----	----	----	---	---	---	---	----
Lacustrine deposits	Entire section	Medium	52	7.8	[a] 1.0	.02	30	9.0	7 6	.5	130	15	3 0	1	.0	140	120	110	7.5	1
		Poor	53	15	[a] 1.8	----	---	----	----	----	---	----	----	----	----	---	---	---	---	----
		Good	44	----	.04	.00	---	----	----	----	---	----	3 0	----	.2	---	70	29	6.3	----
Morainal deposits	Entire section	Medium	49	5.0	.13	.00	26	13	3.5	----	120	21	8.6	<.05	2.0	160	130	110	7.7	----
		Poor	50	----	[a] .36	.02	---	----	----	----	---	----	11	----	7.6	---	180	170	8.0	----
		Good	48	6.7	.08	.01	29	3.8	4.8	.5	140	3.6	4 0	1	.09	160	54	110	7.3	0
Bedrock	Less than 400 feet deep	Medium	50	8.3	[a] .30	.03	41	8.3	11	1.5	170	12	16	1	18	200	90	150	7.7	2
		Poor	52	9.6	[a] .65	.05	51	9.7	64	2.3	250	27	58	.2	.53	310	140	190	8.1	10

a/ Exceeds limits listed in Drinking Water Standards, 1962, issued by the U.S. Public Health Service.

Table 5.--Cross reference of aquifers and water-development areas in the Susquehanna River basin in New York State

U indicates that the corresponding hydrogeologic unit underlies the water-development area.
W indicates that the corresponding hydrogeologic unit is within 1 mile of the water-development area.
Areas as shown in figure 1.

Location		Aquifers									
		Pleistocene									Devonian
		Outwash	Outwash	Outwash	Outwash	Outwash	Outwash	Outwash	Lacustrine	Morainal	Bedrock
County	Water-development area	Less than 50 feet deep; less than 10 feet thick	Less than 50 feet deep; 10 to 40 feet thick	Less than 50 feet deep; greeter than 40 feet thick	50 to 200 feet deep; less than 10 feet thick	50 to 200 feet deep; 10 to 40 feet thick	50 to 200 feet deep; greater than 40 feet thick	Greater than 200 feet deep	Entire section	Entire section	Less than 400 feet deep
Broome	Binghamton	U	U	U	W	U	U			U	U
Chemung	Elmira	U	U	U	U	U			U		U
Chenango	Norwich		U					U	U		U
Cortland	Cortland	W	U			U				U	U
Delaware and Otsego	Sidney		U		U	U		W	U	U	U
Madison	Hamilton	U									U
Otaego	Oneonta		U	U	W			U	U		U
Steuben	Bath			U		U			W		U
	Corning		U	U		U				U	U
	Hornell	W	U	U		U			U		U
Tioga	Owego	W	U	W	W						U
	Sayre-Waverly		U								U

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE U.S. ARMY CORPS OF ENGINEERS
THE U.S. PUBLIC HEALTH SERVICE
THE NEW YORK STATE DEPARTMENT OF CONSERVATION

APPRAISAL OF THE GROUND-WATER RESOURCES OF
THE SUSQUEHANNA RIVER BASIN IN NEW YORK STATE

Topographic base from U.S. Army Map Service, 1950, scale 1:250,000

Figure 5.––PRINCIPAL AQUIFERS IN THE SUSQUEHANNA RIVER BASIN IN NEW YORK STATE

Hydrogeology by Este F. Hollyday, Robert D. MacNish, Allan D. Randall and Robert G. LaFleur.