UNITED STATES
DEPARTMENT OF THE INTERIOR
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WATER RESOURCES DIVISION

AN APPRAISAL OF THE GROUND-WATER RESOURCES OF THE UPPER SUSQUEHANNA RIVER BASIN IN PENNSYLVANIA

(AN INTERIM REPORT)

BY

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AN APPRAISAL OF THE GROUND-WATER RESOURCES OF THE UPPER SUSQUEHANNA RIVER BASIN IN PENNSYLVANIA

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INTRODUCTION

This report describes the availability, quantity, quality, variability, and cost of development of the ground-water resources in the Upper Susquehanna River basin in Pennsylvania, which is the entire drainage area in Pennsylvania above the confluence of the West Branch and the main stem of the Susquehanna River at Northumberland. The report has been prepared for and under specifications established by the Corps of Engineers, U. S. Army, and is intended to serve the specific needs for ground-water information for all Federal and State agencies participating in the comprehensive study of the basin.

A 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 task of preparing a report and of coordinating the work being done by others in support of the study was assigned to the Corps of Engineers. The comprehensive study is being conducted by several Federal departments and independent agencies in cooperation with the States of New York, Pennsylvania, and Maryland.

The comprehensive study is being conducted under the guidelines for river-basin planning set forth by the Congress of the United States. On July 26, 1956, in the 84th Congress, the Senate expressed its sense relative to the conservation and development of water and related land resources in Senate Resolution 281 which stated:

> "Land and water resources development should be planned on a comprehensive basis and with a view to such an ultimately integrated operation of component segments as will insure the realization of the optimum degree of physical and economic efficiency."

The policies, standards, and procedures to be used in the formulation, evaluation, and review of plans for use and development of water and related land resources in river basins are set forth in Senate Document 97, under date of May 29, 1962. These policies, standards, and procedures were prepared by the Secretaries of the Army, Agriculture, Health, Education and Welfare, and Interior and were approved by the President of the United States.

Senate Document 97 in Part III, Section B, states that: "Planning for the use and development of water and related land resources shall be on a fully comprehensive basis so as to consider--

(1) The needs and possibilities for all significant resource uses and purposes of development, including, but not limited to domestic, municipal, agricultural, and industrial uses of water; water quality control; ..., and

(2) All relevant means (including nonstructural as well as structural measures) singly, in combination, or in alternative combinations reflecting different basic choice patterns of providing such uses and purposes."

The consideration of alternative combinations for water supply and water-quality control requires that comparison be made of the use of either surface or ground water. The Geological Survey has been assigned the responsibility of investigating the ground waters of the basin to provide the facts necessary for the action agencies to make such a comparison. It is the only agency directly involved in a study of basin-wide ground-water conditions and potentials.

The report includes facts concerning the geologic and hydrologic parameters necessary for a preliminary evaluation of the role of ground water in the formulation of the comprehensive plan. The report also includes facts on costs of raw ground water delivered at the well head. The cost of ground water is included in response to requirements expressed in Part V, Section E of Senate Document 97 as follows:

"E. Types of primary benefits and standards for their measurement

1. Domestic, municipal, and industrial water supply benefits: Improvements in quantity, dependability, quality, and physical convenience of water use. The amount water users should be willing to pay for such improvements in lieu of foregoing them affords an appropriate measure of this value. In practice, however, the measure of the benefit will be approximated by the cost of achieving the same results by the most likely alternative means that would be utilized in the absence of the project. Where such an alternative source is not available or would not be economically feasible, the benefits may be valued on such a basis as the value of water to users or to the average cost of raw water (for comparable units of dependable yield) from municipal or industrial water supply projects planned or recently constructed in the general region."

In implementing Senate Document 97, the Geological Survey has been assigned by the Susquehanna River Basin Coordinating Committee the responsibility of determining the costs of ground-water sources as "the most likely alternate means that would be utilized in the absence of the project."

The Corps of Engineers and the Federal Water Pollution Control Administration are jointly determining the present and future water requirements of several water-service areas in the basin, as shown on figure 1. They will formulate plans based on the likelihood of supplying these areas with the most economically feasible source of water. They will use this report to determine if ground water is a possible economical source of supply that is comparable with surface-water sources in terms of quantity, dependability, quality, and physical convenience of water use.

The generalized estimates given in the report will be used not only to determine if ground water is likely to be the best choice in any given area, but also in deciding whether it is necessary to further investigate ground water as a potential source of supply in these areas. The decision to recommend the use of either surface or ground water at a particular site will depend almost entirely upon the hydrologic and economic advantages or disadvantages of one source or the other. The actual decisions concerning ground-water feasibility, cost benefits, and the comparison with alternate sources of supply will not, of course, be made by the Geological Survey. The objective of this report is only to present the facts upon which decisions may be based.

The estimated water costs given in this report are based on a series of assumptions. They are valid only for a comparison with surface-water cost estimates being developed by other agencies, and as a comparison between rock units. The costs are to deliver the water to the land surface at zero pressure from individual wells. Because of this general treatment, the figures given are not directly applicable to nor intended for use in the planning and design of individual ground-water development projects. 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.

This report is the third of a series of interim ground-water reports. It is preliminary and subject to revision as the study progresses. In order to facilitate the work on the various agencies involved in the comprehensive study, a system of interim reports has been developed by which the various agencies exchange knowledge.

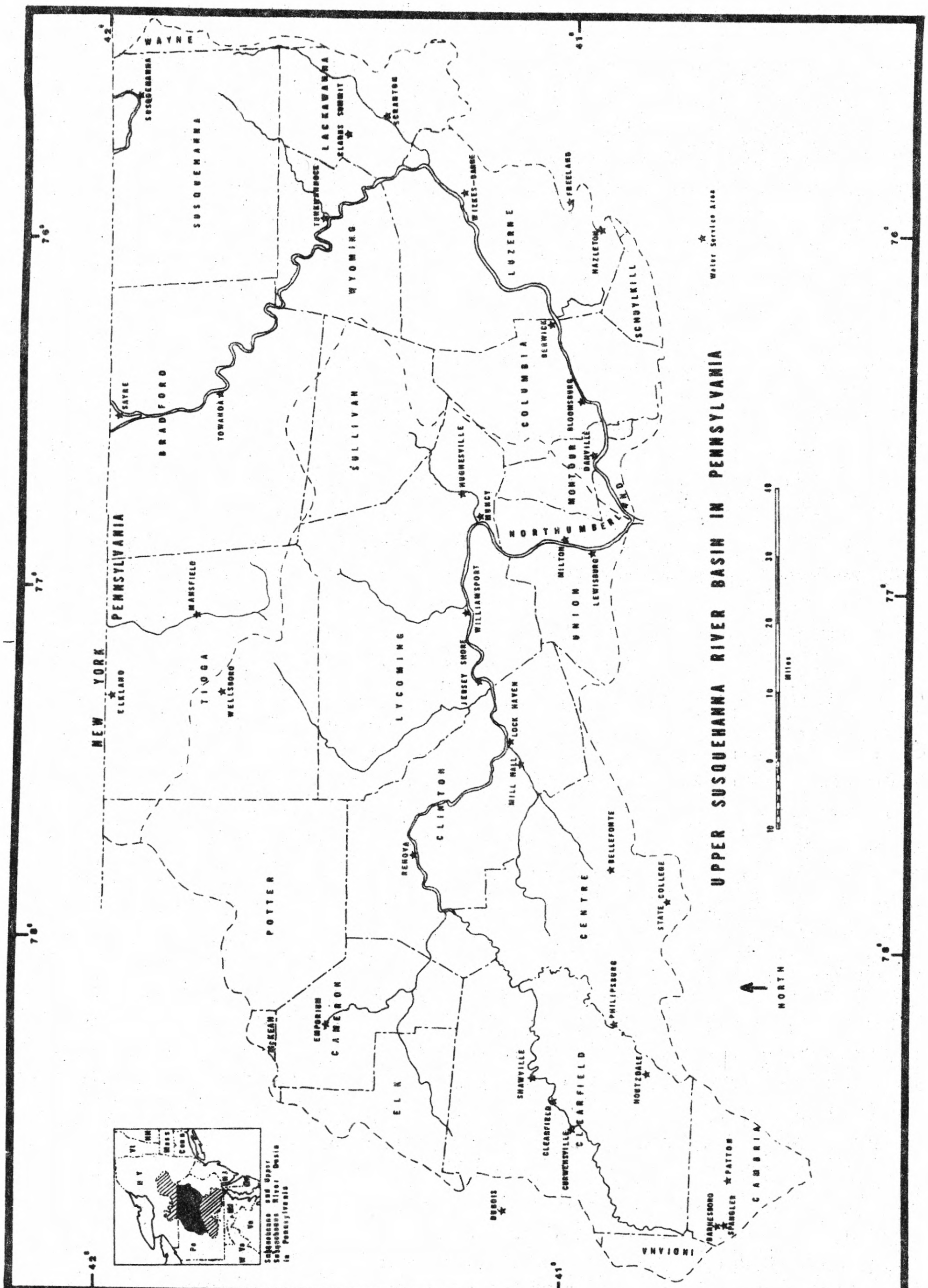

Figure 1.--Map showing designated water-service areas in the Upper Susquehanna River basin in Pennsylvania.

It was agreed that interim information on the ground-water resources would be most useful if reported in a series of four reports on relatively arbitrary subdivisions of the Susquehanna River basin. These subdivisions are: (1) the lower basin, (2) the Juniata River basin, (3) the upper basin in Pennsylvania, which is covered in this report, and (4) the upper basin in New York State. After the interim reports have been completed, a report will be prepared on the ground-water resources of the entire basin.

SUMMARY OF GROUND-WATER RESOURCES

Importance of Ground Water

Ground water plays a vital part 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 over and beneath the land surface.

One major role the ground-water reservoir plays is its modulation of streamflow. In humid areas discharge from ground-water storage maintains the flow of streams during periods of little or no precipitation. In such areas geology determines streamflow characteristics. Streams underlain by shale tend to have flashy runoff characteristics compared to streams underlain by unconsolidated sands. 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 permeability and storage capacity than are basins whose streams have a more uniform flow.

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 resulting in a losing stream. 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.

Ground water can also contribute to dilution and neutralization of acid-mine drainage and reduce its effects downstream, as it does in the Swatara Creek basin near Harrisburg, Pa. Ground water flowing into gaining streams from carbonate rocks contributes alkaline bicarbonate water that neutralizes and dilutes the acid sulfate waters from the coal mining regions upstream. Limestone areas are not plentiful, however, in the upper basin.

At one time ground water could be thought of as a 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 lower cost in time, money, and initial materials 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 total national water-supply requirements (McGuinness, 1963, p. 111). We can foresee ground-water reservoirs not only continuing to be a major source for meeting withdrawal requirements, but emerging as a medium for storing increasingly larger quantities of surplus streamflow for cyclic withdrawal as a phase of multipurpose water management.

Where available in suitable quantity and quality, ground water provides a source of water without the necessity of long transmission lines. In areas where the available supplies of ground water may not equal the utlimately anticipated requirements, it may, nevertheless, 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 at least one-fourth the population of the Susquehanna River basin is estimated to use water derived from underground sources. More than 400 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 difficulties may be inherent in the planning of any large-scale development of ground water. Among them are a lack of detailed knowledge as to occurrence, movement, distribution, and availability for a particular aquifer and complexities in management imposed by outdated or hydrologically incorrect water laws. 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.

Physiographic Provinces

The availability of ground water in any area is determined first by natural conditions--the type, distribution, and structure of the rocks, and the physiography and climate--and second by the extent to which the natural conditions have been changed by the actions of man. Ground-water hydrology in the Susquehanna River basin is particularly complex because of the great variability in both the natural conditions and in the types of changes man has imposed on the system.

The Susquehanna River basin can be divided into three large geologic regions distinguished on the basis of age, character, and structure of the rocks and physiography (McGuinness, 1963, p. 715-729). The availability of ground water and the yield of wells differs from one region to another, but there are many similarities also. The three regions--from south to north--are the Piedmont, the Mountainous Area, and the Appalachian Plateau. (See figure 2.) A fourth region can be considered to include the glacial deposits, which are mainly in the Appalachian Plateau but extend into the other regions. The Upper Susquehanna basin lies within the Mountainous and Appalachian Plateau areas. The southern part of the upper basin lies in the Valley and Ridge Province of the Mountainous Area and the northern part in the Appalachian Plateau Province. The southwestern part of the upper basin lies south of the glacial limit and contains no significant amounts of glacial deposits, whereas the remainder of the upper basin contains glacial deposits.

Mountainous Area

The Mountainous Area, as defined in the Susquehanna River basin, includes the Blue Ridge Province and the Valley and Ridge Province, which includes the Great Valley Section, and occupies the broad northeastward-trending belt between the Piedmont on the south and the Appalachian Plateau on the north. The Valley and Ridge is the only province of the Mountainous Area present in the Upper Susquehanna basin in Pennsylvania. It is underlain by folded and faulted rocks.

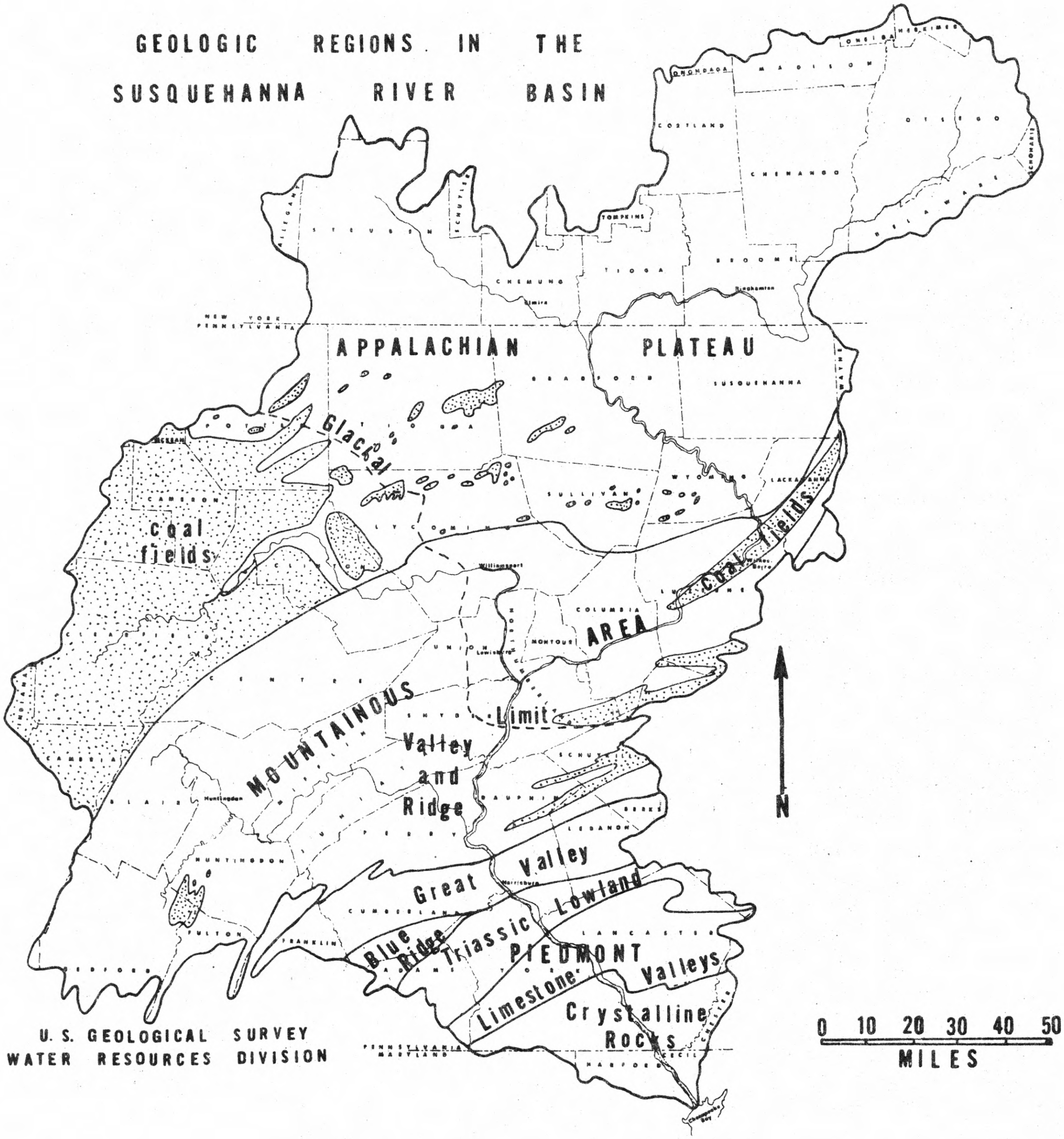

Figure 2.--Map showing the geologic regions in the Susquehanna River basin.

The predominant rock type in the Valley and Ridge Province is a sequence of alternating shale, sandstone, and limestone of Paleozoic age. The rocks in this sequence can yield 20 to 1,000 gpm (gallons per minute) to individual wells--averaging 125 gpm of soft to very hard water. The limestones and dolomites are the most productive aquifers in the Valley and Ridge Province. Large springs, some producing several thousand gallons of hard water per minute, issue from these rocks. The sandstones are potentially good sources of water. Many of the wells that tap sandstones are used only for domestic purposes, as most municipalities are supplied by surface water, but reported well yields of 100 to 500 gpm of soft water indicate the possible importance of sandstones as a source of water. The shales supply water that is generally high in iron and hydrogen sulfide. They generally do not supply more than 75 gpm per well.

Belts of folded shale, sandstone, conglomerate, and anthracite coal, mostly of Mississippian and Pennsylvanian age occur in the southeastern part of the Upper Susquehanna basin. These belts are the Northern Anthracite field (Wyoming-Lackawanna Valley) and part of the Western-Middle Anthracite field. Wells in these rocks yield small to large supplies of water whose quality is generally good, except near coal mines where it is acidic and high in iron as the result of oxidation of sulfides.

The natural ground-water quality in the Valley and Ridge Province differs greatly from place to place and depends mainly on local rock type. The water from sandstone is soft and generally low in dissolved solids, and the water from the Silurian and Devonian limestones is hard and higher in dissolved solids than water from the sandstones.

Water from the Cambrian and Ordovician limestones is only moderately mineralized and moderately hard. The iron content of the water from the sandstones and limestones is areally highly variable. The shales yield water that generally is higher in iron content than that from the limestone but lower than that from the sandstones. Iron-bearing waters are locally called "sulphur waters" in many parts of the area. However, iron, not sulphur, imparts the disagreeable taste and color. Some of the iron-bearing waters also contain hydrogen sulphide, which may produce a precipitate of black ferrous sulphide. These waters locally are called "black sulfur waters."

The rocks in the Mountainous Area have been folded and faulted so that they dip steeply throughout most of the area. This folded and faulted structure results in northeastward trending beds of rocks of different types. The deformation of these rocks decreases northwestward, and ultimately there is a zone in which the folded rocks give way to the nearly horizontal rocks of the Appalachian Plateau.

Appalachian Plateau

The Appalachian Plateau underlies the largest part of the Upper Susquehanna River basin. The rocks are nearly horizontal and are of Devonian, Mississippian, and Pennsylvanian age. They consist of alternating shale, siltstone, sandstone, limestone, and bituminous coal. The rocks of the Plateau have not been widely utilized as a source of water. The easy availability of water from the glacial deposits underlying the valley floors where the urban areas are situated is one reason. Another is the fact that the area contains vast wooded areas in which no wells have been drilled.

Despite the lack of widespread exploration there is evidence that these rocks can yield appreciable amounts of water. Yields of as much as 1,000 gpm have been obtained from wells, but the average yield is about 350 gpm. The water is generally of good quality except near coal mines. The yields of wells should be expected to decrease from east to west and from south to north owing to the increase in the amount of shale in the section westward and northward across the Plateau. The water is generally of poor quality in the western part of the area because of the presence of coal beds. The fresh ground water generally has a low to moderate dissolved-solids content and hardness, but the iron content may be a problem locally, particularly in the coal-bearing sequences. In most parts of the Plateau Province the ground waters at shallow or moderate depths are fresh, whereas those at greater depth, below drainage level, may be brackish or saline. Some of these deep-seated waters are brines that are more highly concentrated than sea water.

The flat-lying rocks of the Plateau contrast sharply with the inclined rocks of the Valley and Ridge. The flat-lying nature of the rocks of the Plateau allows the choice of more than one aquifer at most localities, which is not true of the steeply-dipping consolidated rocks in the southern part of the Susquehanna basin. In many instances, the presence of two or more aquifers allows a choice of both quality and quantity of water.

Glacial Deposits

Glacial till or unsorted glacial material mantles the uplands north of the glacial limit in the northeastern part of the basin and is not known to yield large amounts of water to wells. It yields water of generally good quality and is important as a source of water for domestic wells. Several villages are supplied water of generally good quality by shallow wells and springs in the drift. Further testing of the glacial till would probably reveal many places where properly constructed wells would yield 100 gpm or more.

The most important aquifer within the glacial deposits is stratified drift both within and beyond the limits of the areas once covered by glaciers. The stratified drift, which includes outwash sand and gravel and ancient lake deposits of silt and clay, is found in nearly all the major valleys in the northern part of the basin. The sand and gravel deposits yield moderate to very large supplies of water. Some wells yield more than a thousand gallons per minute. The water from the glacial deposits is generally of good quality. The hardness of the water is related to the drift lithology, being hard to very hard where limestone pebbles are contained in the drift material. Toward the New York border the water is hard and locally contains iron in troublesome amounts. The water is very soft, low in dissolved mineral matter, and almost free of iron in most of the area in Pennsylvania that is underlain by glacial drift. The chemical character of the water in the glacial drift is likely to be affected by the chemical character of surface water where pumping from wells has induced surface-water recharge. Wells and springs in the stratified drift supply many of the largest towns in the Plateau Province.

In general, the stratified drift is the most productive and readily recharged aquifer in the basin, and it yields a considerable part of the half billion gallons per day of ground water pumped in the entire Susquehanna basin. It is also the most promising aquifer for future development, particularly in the part of the basin covered by this report, where the glacial deposits have not been extensively utilized as a source of water supply. In much of the area the glacial deposits are used mostly for domestic supply and have not been tested thoroughly. But the several wells that yield over a thousand gpm indicate the magnitude of yields that can be obtained from properly constructed wells in the outwash deposits.

Ground-Water Problems

The Susquehanna River basin, particularly the Upper Susquehanna River sub-basin, has a humid climate and a large supply of water, and there is no present or foreseeable overall shortage of water. Water related problems are numerous but generally are not as critical as they are in many other parts of the United States. Hence, in this water-rich area, problems of water supply are largely local. There are problems of determining the local availability of water, regulating the use of water to prevent overdevelopment, and protecting the water from contamination.

Availability of Supply

Locating ground-water supplies is a problem in many places in the Upper Susquehanna River basin because of the complexity of the geology and hydrology. Existing reports form a good basis for detailed studies of areas of prospective development, but only a start has been made on the detailed studies. The basin is underlain by a great variety of rocks that differ greatly in their areal extent, composition and texture, thickness, structural attitude and relation to each other, and in their physiographic expression. All these factors affect the rocks' capacity to store and transmit water. Much study is needed to support more accurate predictions of just where and how deep it will be necessary to drill, what quantity and quality of water can be expected, and what will be the hydrologic effects of withdrawing water at various rates.

Ground-water conditions differ not only from one stratigraphic unit to another, but also differ within a given unit. Hence, though it is possible to generalize about ground-water conditions over large areas, it is rarely possible to predict accurately the availability of ground water at a specific locality in the Upper Susquehanna River basin in advance of drilling--even if wells of known performance are nearby.

Overdevelopment

Overdevelopment of ground water is presently a problem in very few areas in the Upper Susquehanna River basin. On the whole, much additional ground-water development is feasible. The ground-water resources appear to be ample to meet future needs, and the problems that may develop are those of distribution of the supply--not of the total resource. Where development is intense in the Susquehanna River basin--such as in lower Broome County, New York, or at State College, Pennsylvania--legal control to prevent overdevelopment or contamination may be necessary.

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. In any area the size of the Upper Susquehanna River basin there may be found rural or suburban householders, or small communities in unfavorable ground-water areas, that have spent several thousand dollars in drilling wells and still do not have an ample supply. In general, however, the ground-water supplies have met the demands reasonably placed upon them. Enough water for full-scale irrigation of a very large acreage from one or a few wells is usually available only from the glacial deposits. Enough water for irrigation of small acreages from a few wells or from many wells over a large acreage is generally available at a reasonable cost.

Contamination

Contamination is sometimes a major problem with ground-water supplies as it often is with surface supplies. Population expansion and heavy industrialization have combined to produce large quantities of pollutants. Coal mines, either active or abandoned, are one of the main sources of pollutants in the Upper Susquehanna Basin in Pennsylvania. Though streams are the principal recipients of acid mine wastes, ground water may also be affected in any area where coal beds occur. Contamination of ground water by domestic or industrial wastes is a potential threat in s ome expanding urban areas. In valleys underlain by cavernous limestone in the basin, contamination of ground water by sewage and industrial wastes is common.

A type of contamination whose extent and importance are only beginning to be realized is that resulting from movement of rainwater and snowmelt through sanitary land fill and, thence, into aquifers and streams. As population grows and accumulates solid waste products, which are disposed of by filling low areas, the problem is bound to increase and utlimately will necessitate remedial action.

As the practice of returning heated water (which has been used for cooling) to the ground increases, thermal pollution will become an increasingly serious problem in some areas.

An increasing variety of contaminants are being produced by industries using chemical processes. Other contaminants including synthetic detergents, pesticides and insecticides, fertilizers, and radioactive substnaces are being used in growing amounts. Most of these newer contaminants are of unknown and possibly high toxicity, or are difficult to remove from water, or both. All these contaminants tend to find their way into our water supplies. Against most of them, however, ground waters are better protected than surface waters. Once contaminated, however, ground-waters tend to remain contaminated longer than surface waters because the contaminant may be difficult to remove from the ground and because the relatively slow velocity of ground water results in a longer flushing time.

EXPLANATION OF DATA AND TERMS USED IN THIS REPORT

Geologic

The reader is referred to the Geologic Map of Pennsylvania (Pennsylvania Geological Survey, 1960) for the location of the geologic units discussed in this report except for the glacial deposits which are shown on figure 3 in this report and also in part in Lohman (1939, plate 2). The stratigraphic nomenclature and age assignments used in the Geologic Map of Pennsylvania differ only slightly from those approved for use by the U. S. Geological Survey. No confusion will therefore result from simultaneous usage of the map and this report.

Hydrologic

The following hydrologic terms are used in this report as indicated.

Aquifer

An aquifer is a hydrologic unit comprising water-bearing rocks from which water is collectable in usable quantities. Aquifers are of two principal kinds: water table (unconfined) and artesian (confined). An aquifer may be a single geologic formation, a part of a formation, or two or more formations that are hydraulically connected to form a single aquifer. In this report, the terms aquifer and ground-water reservoir are considered synonymous. Aquifers serve as both underground reservoirs and a pipelines, for in addition to storing water they transmit it from places of recharge to places of discharge.

Specific Capacity

The rate of yield of a well per unit drawdown of water level is known as the specific capacity of the well. Thus, a well yielding 100 gpm with a drawdown of 5 feet has a specific capacity of 20 gpm per foot of drawdown. Specific-capacity data provide a basis for comparing wells of different yields and estimating the hydraulic properties of the aquifer units thus tested. It is not an exact measure of the hydraulic properties of the aquifer units thus tested because of effects of the internal characteristics of the borehole. Because of well-losses--well-efficiency being less than 100 percent--the specific capacity of wells will vary even within a uniform aquifer. However, in this study it was assumed that well drilling and development techniques in the future would be the same as those of the past. Therefore, the recorded specific capacities would be representative of those to be obtained in the future.

Availability

The term "availability" is used in this report in a special sense to indicate the accessibility and location of aquifers with respect to a given municipality, township, or water-service area. Sections of the report concerned with availability will deal with the location of geologic units, in the area under discussion, that are capable of yielding usable ground-water supplies. All such units listed as available to an area are inside of or within 1 mile of the political boundaries of that area.

Quantity

The quantity of water that can be obtained from a single hypothetical well is computed from specific-capacity data and from assumed available drawdowns, and is based on a statistical analysis of records obtained chiefly from existing successful municipal and industrial wells. Such wells were used for the analysis because usually an effort is made to obtain the largest possible yield from municipal and industrial wells. In contrast, domestic wells are usually developed only to the extent necessary to provide a supply for one household. Records of domestic wells were used sparingly or eliminated from the analyses.

Well yields in gallons per minute often depend as much upon the effort made to obtain water from the well as upon the characteristics of the aquifer. For instance, a larger diameter well, a larger capacity pump, a deeper pumping level, a deeper well, or additional well development may all result in an increased well yield. Partial penetration of the aquifer, well loss, and geohydrologic boundaries may affect specific-capacity data. The use of specific-capacity data allows the computation of well yields in gallons per minute for any well diameter or depth if a static water level and available drawdown are known. This assumes that specific capacity is uniform with depth; that is, with increased penetration of the aquifer. The specific-capacity data used in this report are those obtained, for the most part, at the time the well was first constructed. Specific capacities theoretically decline as time passes if all pumpage is from storage in the rocks. The reported specific capacities were, therefore, all adjusted to what they theoretically would be after 180 days of pumping without recharge. In addition, specific capacities sometimes vary seasonally, usually being higher in the winter than in the summer owing to higher natural static water levels in the winter.

By using the median figure for specific capacity and yield data shown in table 1, a reasonable estimate of predicted well yields is obtainable. The quantities listed in later sections of this report as being available from each geologic unit or to any specific area are based upon reasonable predicted yields of single wells. The wells are assumed to be located by an experienced engineer or geologist and not to be affected by the pumping of any other well.

In recent years, great progress has been made in the scientific spacing, design, construction, development, and maintenance of wells. The design and operation of a well or of well fields, to recover the maximum yield of ground water, are the responsibility of specialists outside of the Geological Survey.

Data are generally insufficient in the Upper Susquehanna River basin to permit applying theory to the problem of well spacing over large areas, but there is the opportunity for steady improvement in the design of individual well fields in localities where the required data are available or can be obtained.

There is an upper limit to the amount of ground water that can be obtained from an area on a long-term basis, just as the watershed above a surface reservoir can be expected to provide only certain amounts of water. Estimates made in the adjacent Delaware River basin (Parker and others, 1964, p. 91) of 0.75 mgd (million gallons per day) per sq mi of natural ground-water recharge for similar rocks give some indication of the amount of ground-water available to this area. Either more or less than 0.75 mgd may be available for consumptive use in any particular area, depending on local conditions. Generally less will be available in areas remote from major streams and much larger amounts will generally be available near major streams. However, the major limiting factor for ground-water availability will be the transmitting and storage capacity of the major rock units in the basin. Because of the relatively low productivity and small storage capacity of many of the rock units, and also because of many practical limitations, chiefly economic, only a small part of the ground-water discharge at natural outlets in the Upper Susquehanna River basin can be diverted for man's use. However, pumpage substantially in excess of the 1968 rate could be maintained with increased ground-water development. The general assumption can be made, however, that all the water necessary to 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. However, the total quantity or sustained yield of a particular area cannot generally be predicted without further study. The cost in time, materials, and personnel necessary to determine the "safe yield" of even a small area is high.

No water-requirement figures were supplied to the U. S. Geological Survey for any of the water-service areas designated; therefore, no estimates of the available supply in terms of requirements can be made. The terms inadequate or abundant supply of water are meaningless unless judged against requirements. For example, a supply of 1 mgd is inadequate for any industry needing 5 mgd, but would be abundant for a town needing only 0.1 mgd.

METHOD OF ANALYSIS

For the sake of uniformity, the analyses in this paper are based upon hypothetical wells of a uniform depth and diameter for assumed conditions. The characteristics of the hypothetical wells are made to conform to the characteristics of the aquifers by an analysis of existing wells of various depths and diameters. A brief discussion of the general approach used in this report follows. More detailed explanations are given in the section of the report entitled "Explanation of Tables."

A list of 35 water-service areas chosen by the Federal Water Pollution Control Administration and the U. S. Army Corps of Engineers in the Upper Susquehanna River basin were analyzed to meet the objectives of the Comprehensive Study of the basin. All geologic units occurring in or within 1 mile of these areas were tabulated. Specific-capacity, geologic, hydrologic, and well-record data were collected and organized for wells tapping these units. The specific-capacity data were analyzed statistically by plotting specific capacities of wells against percentage of wells on logarithmic-probability paper. The reported specific capacities were all adjusted to what they would theoretically be after 180 days of pumping with no recharge. Static water levels were estimated for each geologic unit. Pumping water levels were assumed for major rock groups: 50 feet for unconsolidated sand and gravel deposits, 100 feet for carbonate rocks, and 200 feet for the sandstones, shale, and other rocks. Available drawdowns for each geologic unit were then obtained by subtracting the static water level from the pumping water level. It was assumed that any well yielding less than 10 gpm would be considered unsuccessful, and the specific capacities that would result in such yields were eliminated from the distribution on the graphs.

The specific capacities that would result in yields above 10 gpm were redistributed. Specific capacities at the points equalled or exceeded in 75 percent, 50 percent, and 25 percent of these successful wells were picked from the new distribution graphs. These specific capacities were multiplied by the available drawdown to obtain a range in the quantity of water available from each rock unit in terms of gallons per minute per well. These yields were classified as poor, medium, and good and correspond to the 75, 50, and 25 percent categories of specific capacities, respectively. Continuous pumping of 24 hours a day for 365 days a year was assumed in the computation of daily and yearly well yields.

Wells were then designed using the computed probable yields to obtain a range in probable costs of ground water delivered at the well head. Completed well depths were chosen to be 100 feet in sand and gravel, 300 feet in carbonate rocks, and 400 feet in all other rock types. Well diameters were selected on the basis of pump size, which in turn were based on the anticipated yield of the well. The length of casing was selected as 40 feet in all rock wells and 80 feet in sand and gravel wells. Deep-well turbine units for each hypothetical well were selected to produce the anticipated yields at the smallest value of pump working horsepower from the assumed pumping levels.

The costs of the ground water from these hypothetical wells were then found by compiling the initial costs to construct the well and computing the cost of operation and maintenance, which includes depreciation and power costs. The total annual cost of producing the water was divided by the amount of water produced from each well to arrive at ground-water costs.

The costs estimated for well construction, that is, initial costs, were obtained from published reports and from industries, such as well drilling firms that install such equipment. These initial costs include only those costs necessary for works to collect the water, and do not include costs to treat or distribute the water. The initial costs include costs to drill an exploratory well and to drill, develop, and pump test the production well; equipment, including casing, strainer, screen, pump, column, shaft, motor, meter, local piping, pumphouse, and electrical controls; land and rights of way; and contingencies and engineering, including administration.

The costs of the annual payment to retire the initial cost of the well installation were found by amortizing the initial cost of the well at 4 percent over a period of 25 years by the capital-recover-factor method of cost accounting.

Annual power rates were based upon Pennsylvania Power and Light Company electric power rate schedules for municipal use, assuming 24-hour a day use and 75 percent wire to motor efficiency. Annual maintenance costs were estimated from data obtained from the Pennsylvania Utility Commission and taken as 4 percent of the initial cost of the equipment.

The total annual cost to operate a single well was then taken as the sum of the annual payments to retire the initial cost, the power cost, and the annual maintenance cost. The costs in dollars per thousand gallons were found by dividing the total annual cost by the production figure from each well in thousand gallons per year. The costs in dollars per million gallons a day were found by dividing the total annual cost by the production figure from each well in million gallons per day and reported as the average annual cost in dollars per million gallons a day of the design yield. This cost figure is only valid 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-service 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.

EXPLANATION OF TABLES

The estimated specific capacity and the yield of the hypothetical wells are summarized in table 1. The design of the hypothetical wells is summarized in table 2. Estimates of the cost of the hypothetical wells and of the cost of obtaining ground water from them are summarized in table 3. Representative chemical quality of ground water in each geologic unit is summarized in table 4. A cross reference of geologic units and water-development areas is given in table 5. Following is an explanation of the reference columns introducing data tabulated in tables 1, 2, 3, and 4.

The geologic formations or groups are listed according to increasing geologic age. Only those units that could be considered as aquifers, and for which well data are available, area listed. The geologic names and ages are those in current usage by the U. S. Geological Survey. The symbols used are those shown on the Geologic Map of Pennsylvania (Pennsylvania Geological Survey, 1960). The name of the geologic unit is given on all four tables, whereas the age and symbol are given only in table 1. The geologic age given is that formal period (or periods) in geologic time when the geologic rock unit is believed to have been formed. The first letter of each symbol indicates the period in geologic time. Succeeding letters in each symbol indicate the name of the geologic unit. These symbols may be found within colored rectangles in the legend of the Geologic Map of Pennsylvania and within corresponding color patterns on that map.

Table 1.--Specific Capacity and Yield of Hypothetical Wells

For this report, the hydraulic properties of aquifers were estimated on the basis of geologic maps, water levels, and specific-capacity data. High specific capacities generally indicate that the rocks are capable of transmitting large quantities of water, and low specific capacities generally indicate the rocks are capable of transmitting only small quantities of water. The specific capacity of a well cannot be an exact criteria of the ability of the rock to transmit water, because specific capacity is often affected by partial penetration, well losses, and hydrologic boundaries. These factors may adversely affect specific capacity; thus, the actual transmitting properties of the rocks are usually greater than those computed from the specific-capacity data.

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 gpm/ft

Q = discharge, in gpm

s = drawdown, in feet

T = coefficient of transmissibility, in gpm/ft

S = coefficient of storage

r_w = nominal radius of well, in feet

t = time after pumping started, in minutes

In addition to the assumption of an idealized aquifer as given above, the equation assumes that: (1) the well penetrates the total saturated thickness of the aquifer, (2) well loss is negligible, and (3) the effective radius of the well has not been affected by the drilling and the development of the well and is equal to the nominal radius of the well.

Hence, the specific capacity of any individual well is dependent upon the following: the transmissibility of the rock, the storage coefficient of the rock, the pumping period, well losses, effective well radius, the effects of partial penetration, and geohydrologic boundaries.

The productivity of wells tapping even an ideal aquifer, therefore, differs greatly from place to place depending upon all the above factors. The geologic units in the Upper Susquehanna River basin are not idealized aquifers; hence, it is impossible to predict with a high degree of accuracy the yield of a single well at any specific location before drilling. In fact, it might be possible to drill what is essentially a "dry hole" at any location in the area. However, methods of statistical analysis can be a great help in appraising the role of individual geologic units as producers of water. In this way, the probable range of specific capacities of wells can be estimated based on frequency graphs. Specific-capacity data were available for wells penetrating each of the several units under consideration, and these data were used to estimate the range of productivity and the relative consistency of the productivity of the units.

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

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

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.

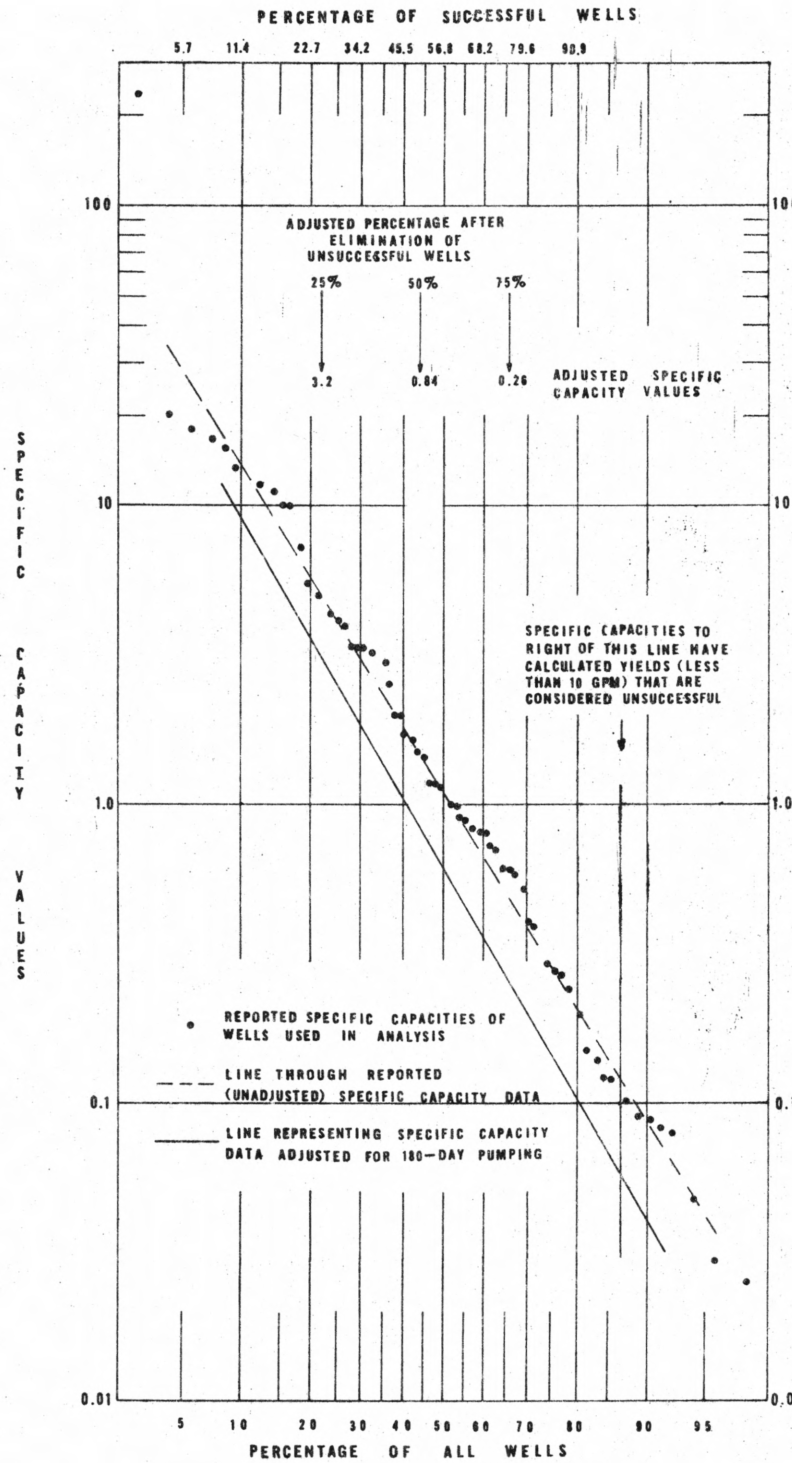

Figure 4.--Specific capacity frequency distribution graph for the Catskill Formation aquifer in the Appalachian Plateau.

Specific capacities were then plotted against percentage of wells on logarithmic-probability paper. (See figure 4 as an example of such a plot.) Straight lines were fitted to the data. The slope of the specific capacity-frequency graph varies with the variability of production, a steeper line indicating greater range in productivity.

Yields of the aquifers at specific wells were estimated from the specific capacity-frequency graphs, which, in turn, were based on areal geologic maps, water-level data, and well-production data. Well yields were estimated on the basis of the specific capacities equaled or exceeded in 75 (poor), 50 (medium), and 25 (good) percent of the existing wells. Specific capacities (see table 1) were multiplied by the 180-day drawdown (see table 2) to determine the probable yields (see table 1).

As can be seen in equation (1), specific capacities theoretically decrease with time during periods of continuous pumping. Specific capacities used in this analysis were obtained at various pumping rates and for various periods of continuous pumping, which were 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. The figure used was that of 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 one-half 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 average for a well pumped 24-hours a day for 365 days a year. In practice, the well would most likely be pumped no more than 12 hours a day and allowed to recover for at least 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 excessively tedious 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 water-table coefficient, was used to adjust the specific-capacity data. This is a conservative figure to use for the computations of 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 a smaller or artesian coefficient of storage.

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, that percentage of the sample having a specific capacity that would result in a yield of less than 10 gpm was eliminated from the distribution. For wells tapping glacial deposits this was a specific capacity of less than about 0.33, for wells tapping limestone aquifers this was a specific capacity of about 0.12, and for wells tapping shale and sandstone aquifers this was a specific capacity of about 0.05. For only one geologic unit, the combined Keyser and Tonoloway Formations, were more than 25 percent of the wells eliminated. The remaining percentage of specific capacities of successful wells was redistributed. Specific capacities exceeded in 75, 50, and 25 percent of these successful wells were picked from the new distribution graph and reported in table 1. When considering the cost of wells and ground water (in order to account for the unsuccessful wells that were eliminated) it was assumed that two wells in consolidated rocks and four wells in unconsolidated deposits would be contracted and drilled in every formation to obtain one successful well (see page 29). It was further assumed that the well sites actually chosen would be based upon the best of engineering, geologic, and well-construction advice. The sites of all wells used in the analysis may not all have been selected on the basis of such expert advice.

Even though the above assumptions may have very little relationship to the actual yield of a specific well, it is believed that the resulting figures are realistic for the formation as a whole, and are probably conservative. This method appears to give some basis for estimating what long-term yields may reasonably be expected from a series of wells drilled in a particular aquifer.

Following is a discussion of some of the columns listed in table 1:

Specific-Capacity Data

Specific capacity exceeded by indicated percentage of successful wells

75 percent.--This figure represents the specific capacities estimated to be equaled or exceeded in 75 percent of existing successful wells. It is considered to represent a poor specific capacity expected in the prediction of the productivity of the geologic unit under discussion.

50 percent.--This figure represents the specific capacities estimated to be equaled or exceeded in 50 percent of the existing successful wells. It is considered to represent a medium specific capacity expected in the prediction of the productivity of the geologic unit under discussion.

25 percent.--This figure represents the specific capacity estimated to be equaled or exceeded in 25 percent of the existing successful wells. It is considered to represent a good specific capacity expected in the prediction of the productivity of the geologic unit under discussion.

Number of Wells Used for Specific-Capacity Frequency Distribution Analysis

This column refers to the number of wells in the geologic unit for which specific-capacity data were available. The number listed is an indication of the reliability to be placed upon the analysis of the specific-capacity data. The greater the number the better the results of the analysis.

Percentage of Unsuccessful Wells

This column refers to the percentage of wells in the original data analyzed having an adjusted specific capacity that would result in a yield of less than 10 gpm. For the glacial deposits this was a specific capacity of less than about 0.33, for limestones and related carbonate rocks a specific capacity of less than about 0.12, and for all other rocks a specific capacity of less than about 0.05. This number is partially a reflection of the number of domestic wells used in the analysis and partially a reflection on the chance of drilling an unsuccessful well in the aquifer.

Yield Exceeded by Indicated Percentage of Successful Wells

The yields given in gallons per minute represent the probable yields for the 75 percent (poor), 50 percent (medium), and 25 percent (good) specific capacities multiplied by the available drawdowns given in table 2. Three-quarters, one-half, and one-quarter of existing wells, respectively, should yield this amount of water if pumped to the drawdowns given in table 2. The yields given in million gallons per day represent the yields in gallons per minute multiplied by 1,440. The yields given in million gallons per year represent the yields in gallons per day multiplied by 365. The yields in million gallons per day can be converted to cubic feet per second by multiplying by 1.55.

Table 2.--Design of Hypothetical Wells

The design of the hypothetical wells is summarized in table 2. Following is a discussion of some of the columns listed in table 2.

Well Depth (feet)

It was decided to drill all hypothetical wells in the sand and gravel deposits to a depth of 100 feet, in limestones and related carbonate rocks to a depth of 300 feet, and to drill all wells in other types of rocks to a depth of 400 feet. Almost all of the major valleys are filled with glacial deposits to a depth of at least 100 feet in the glaciated part of the basin. Studies have shown that the majority of solution openings in limestones and related carbonate rocks occur above a depth of 300 feet. Other studies have shown that the majority of fractures and joints in other types of rocks, such as sandstone and shale, occur above a depth of 400 feet. Hence, the depth of drilling was selected on the basis that the wells would penetrate almost all the water-bearing openings in the rocks to be drilled. At any given site, it may not be necessary in actual practice to drill to the above listed depths to obtain the indicated quantity of water, or drilling may proceed to greater depths without success in obtaining the indicated yield.

Well Diameter (inches)

The diameter of the well selected in inches was based on the pump size, which in turn was based on the anticipated yield of the well. The relationship of the anticipated yield of the well to the well diameter and pump size is shown in the table below:

Yield in gallons per minute	Pump size in inches	Well diameter in inches
0 - 100	4	6
100 - 250	6	8
250 - 500	8	10
500 - 1,000	10	12
1,000 - 1,500	12	14

Length of Casing (feet)

Examination of the existing data and discussion with well drillers revealed that generally 40 feet of casing was installed for large-capacity municipal and industrial wells, regardless of consolidated rock type. Hence, 40 feet of casing was used as the average length installed for all the wells tapping consolidated rocks. For the unconsolidated sand and gravel aquifers, 80 feet of casing was used because it was decided to drill all hypothetical wells to 100 feet and to install 20 feet of screen.

Static Water Level (feet below land surface)

The figure given is an approximate average of the water-level data available for each geologic unit. Ground-water levels fluctuate greatly throughout the year. The fluctuations are controlled by geologic, climatic, and hydrologic factors, and by the activities of man. At any given instant, water levels in a particular aquifer are not everywhere at the same level. Furthermore, the water levels given would certainly not be the same throughout the year. The figure shown is only an estimate; therefore, even if available data indicated a higher static water level, a static water level of 20 feet below land surface was used in the computations. Accordingly, 20 feet below land surface is the highest static water level shown in table 2.

Pumping Water Level (feet below land surface)

A pumping water level of 50 feet was used for the unconsolidated glacial sand and gravel deposits. A pumping water level of 100 feet was used for most limestones and related carbonate rocks. A pumping water level of 200 feet was used for all the other rocks, such as the sedimentary sandstones and shales. These levels were chosen so that at least one-half of the water-bearing openings in the rocks would be below the pumping water level.

Though these pumping water levels were selected without sufficient knowledge of the geohydrologic framework, they are probably the maximum depths to which the static water levels may be drawn down due to pumping without seriously impairing the water-yielding capacities of the aquifers. They were chosen to give the largest yields under any given set of conditions.

The pumping water level, as well as the drawdown, are each separated into subheadings for poor, medium, and good yields, in order to show the pumping water levels and drawdowns in those rare cases where the computed maximum yields in carbonate rocks would exceed 1,000 gpm if a pumping water level of 100 feet were used.

Drawdown (pumping water level minus static water level in feet)

Drawdowns calculated from values listed under static water-level and pumping water level are considered probable maximum available drawdowns. These values were multiplied by the corresponding specific capacities given in table 1 to obtain the estimated yields given in table 1.

Pump Working Horsepower

Pump working horsepower for a given hypothetical well is the actual working power necessary to lift the corresponding yield given in table 1 from the corresponding pumping water level given in table 2 to the land surface, hence, at zero pressure. Pump bowl horsepower (HP) was computed from the following formula:

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

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

Table 3.--Cost of Hypothetical Wells and of Ground Water

The feasibility of ground-water development is here defined to mean whether or not ground water can be managed or utilized successfully. The assumption is 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 ground-water reservoirs are capable of being used feasibly is to a large extent a matter of cost of water. This section deals with the cost of developing ground water, and these costs are summarized in table 3.

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 discuss only those costs related to the collection of water. The U. S. Army Corps of Engineers are developing costs for the treatment and conveyance of the ground water.

The costs of works for the collection of water, or for the construction, operation, and maintenance of the hypothetical wells, may be broken down into (1) initial costs and (2) annual costs. The initial costs are those costs to initially construct the well. The annual costs are those costs to operate and maintain the well, which include costs to amortize the initial cost, power costs, and maintenance costs.

For ground-water development initial costs at the 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, and inside piping; (3) pump house and electric lines and controls; (4) land and rights of way; and (5) contingencies and engineering, including administration.

Initial Costs

Costs 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 vary from place to place and from time to time. The costs will vary with the regional location of the well, the geohydrologic setting at the well, the well construction and methods used in well construction by the contractor, and the need of each contractor bidding to obtain the construction contract. The costs are September 1964 prices and can be converted to approximate present prices by comparison with the Engineering News-Record Construction Cost Index, which was 947 in September 1964. (Eng. News-Rec., vol. 173, no. 12, p. 93).

The factors considered in arriving at the initial cost of the wells are discussed in the following sections. The numbers given refer to the numbers of the column headings in table 3.

1.--Drilling wells

The depth, casing length, and diameter of the proposed well are discussed in the section on well design. One exploratory well (which could later be converted to an observation well) for every production well in consolidated rock aquifers was assumed to be a reasonable average for the area. For the unconsolidated sand and gravel aquifers, three exploratory wells of 6-inch diameter for each production well of specified diameter were estimated to be a reasonable average. This allows for the additional well or wells to be used in determining the hydraulic properties of the aquifer in the area and for monitoring water-level fluctuations. The estimated cost of drilling each well by percussion or cable-tool method in various rock types in the area is shown in the following table. These figures 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 at the Harrisburg office of the Pennsylvania District. It should be emphasized that they are merely estimates and not what actually may be charged in any specific location or circumstance.

Estimates of costs of drilling and casing hypothetical wells in consolidated rock aquifers in the Upper Susquehanna River basin.

Diameter of well (inches)	Shale (400 feet) (dollars)	Sandstone and quartzite (400 feet) (dollars)	Limestone and related carbonate rocks (300 feet) (dollars)	Casing surface to 40 feet (dollars)
6	$1,200	$1,600	$1,300	$140
8	1,800	2,600	2,800	200
10	2,600	3,800	3,700	280
12	3,400	5,000	4,900	400

Estimates of costs of drilling and casing hypothetical wells in unconsolidated sand and gravel aquifers in the Upper Susquehanna River basin.

Diameter of well	Drilling (100 feet) (dollars)	Casing (80 feet) (dollars)	Screen (20 feet) (dollars)	Total cost (dollars)
6	$ 450	$ 320	$ 850	$1,620
8	800	480	1,110	2,390
10	1,250	640	1,570	3,460
12	1,800	1,000	2,060	4,860
14	2,450	1,240	2,500	6,190

2.--Pump testing production well

Pumping tests of 24-hours duration on the production wells for consolidated rock aquifers and 48-hours duration for unconsolidated sand and gravel aquifers were deemed satisfactory for designing the deep-well turbine pumping unit. A pumping test on a well that would need a pump less than 10 inches in diameter was estimated to cost $500 for consolidated rock aquifers, and a pumping test on a well that would need a pump equal to or greater than 10 inches in diameter was estimated to cost $800 for consolidated rock aquifers. For unconsolidated sand and gravel aquifers, a pumping test on a well needing a pump equal to or less than 10 inches was estimated to cost $1,200 and on a well needing a pump equal to 12 inches was estimated to cost $2,400.

3.--Casing production well

The casings in the production wells are all designed to be 40 feet long for rock aquifers and 80 feet long for sand and gravel aquifers. A screen 20 feet in length was designed for all sand and gravel wells. The estimated cost of casings and screens of various diameters, delivered and installed in the well, were shown in the preceding table.

4.--Motor, column, shaft, pump, and strainer (deep-well turbine unit)

Cost curves were developed relating the cost of deep-well turbine units to well yields for the designed pumping water levels of 100 feet, 150 feet, and 200 feet. (See figure 5.) Costs of the equipment were obtained from current manufacturers price tables. Yields were arbitrarily chosen from the estimated yields reported in table 1. Units designed to yield 1,000 gpm at pumping water levels less than 100 feet in carbonate rock aquifers were individually computed.

5.--Fixed land and equipment cost

The estimated cost of land and rights of way is $1,000 per well. The estimated cost of the pump house is $1,500 per well. The estimated cost of other equipment (wiring, meter, piping, and appurtenances) is $1,500 per well. Thus, the total fixed cost in column 5 is $4,000 per well.

6.--Contingencies

The allowance for contingencies is 10 percent of the estimated construction and equipment costs (sums of columns 1 through 5).

7.--Engineering and administration

The allowance for engineering, including contract administration and financing, has been set at 15 percent of the total construction cost, including contingencies (sum of columns 1 through 7).

8.--Total initial cost

The total initial cost (sum of columns 1 through 7) is the initial cost of a single well, ready to discharge the corresponding yield given in table 1 at the land surface.

9.--Total initial cost in dollars per million gallons a day of design yield

The total initial cost in thousands of dollars per million gallons per day added to the system at the well head is given to allow a comparison between alternative sources of water supply. The total initial cost in column 8 of table 3 was divided by the corresponding yield in million gallons per day given in table 1.

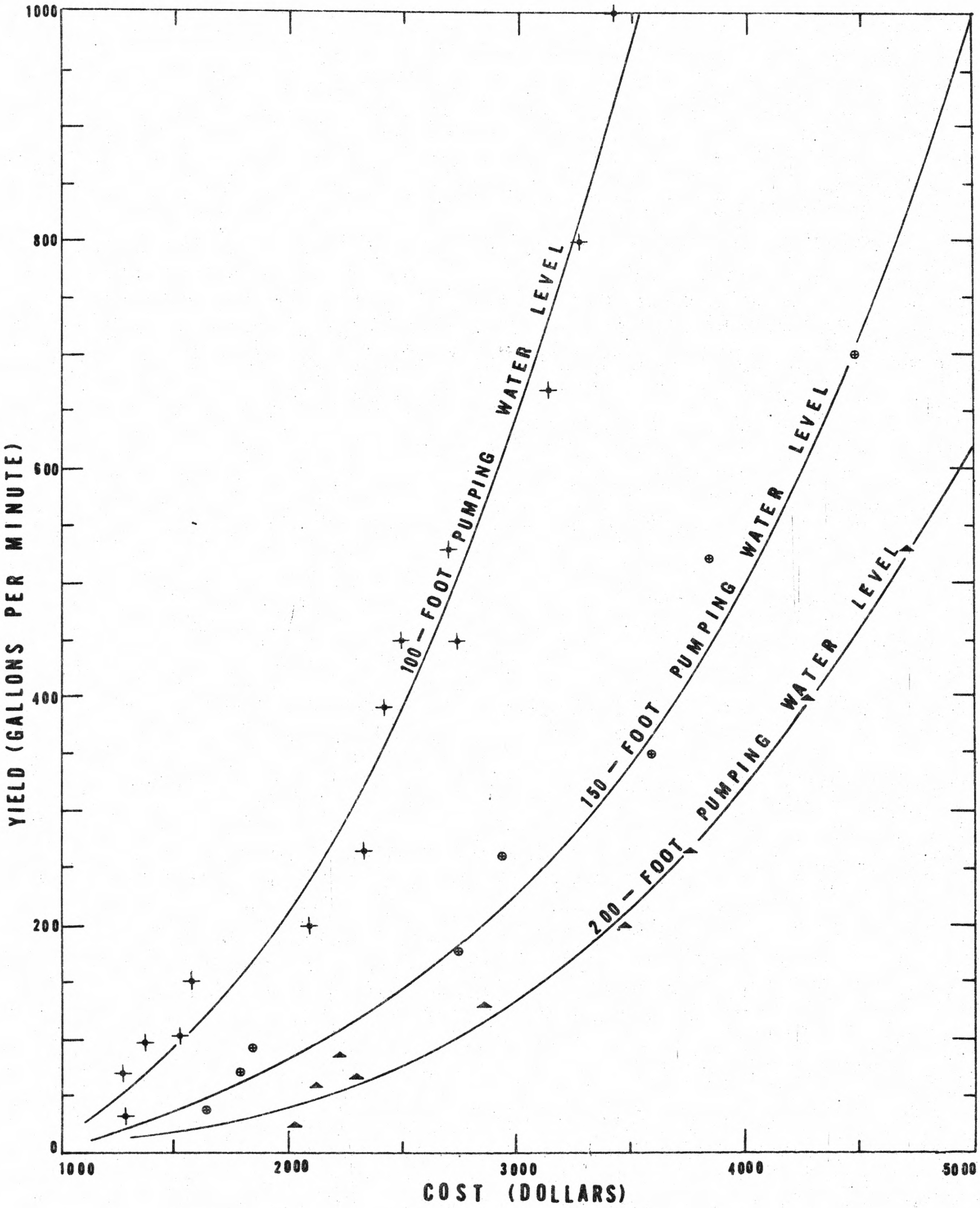

Figure 5.--Graph showing the relation of yield of hypothetical wells to cost of motor, column, shaft, pump, and strainer for selected pumping water levels.

Annual Costs

10.--Annual payments to retire initial cost

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, 1968, p. 45):

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

in which:

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

P = Total initial cost - column 8.

I = Annual interest rate, taken as 4 percent on municipal bonds in this case.

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

$\frac{i\,(1 + i)^n}{(1 + i)^n - 1}$ = 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.

11.--Annual power costs

Annual power costs used herein were based upon Pennsylvania Power and Light Co.'s electrical power rate schedules SGS and LP-3 for municipal use (September 1964). Total power consumption was estimated by using the operating horsepower of the individually designed pumping equipment from table 2, by assuming a 24-hour day use, and by assuming 75 percent wire to motor efficiency so that 1 horsepower equals 1 kilowatt. Figure 6 was used in the calculations of annual power costs.

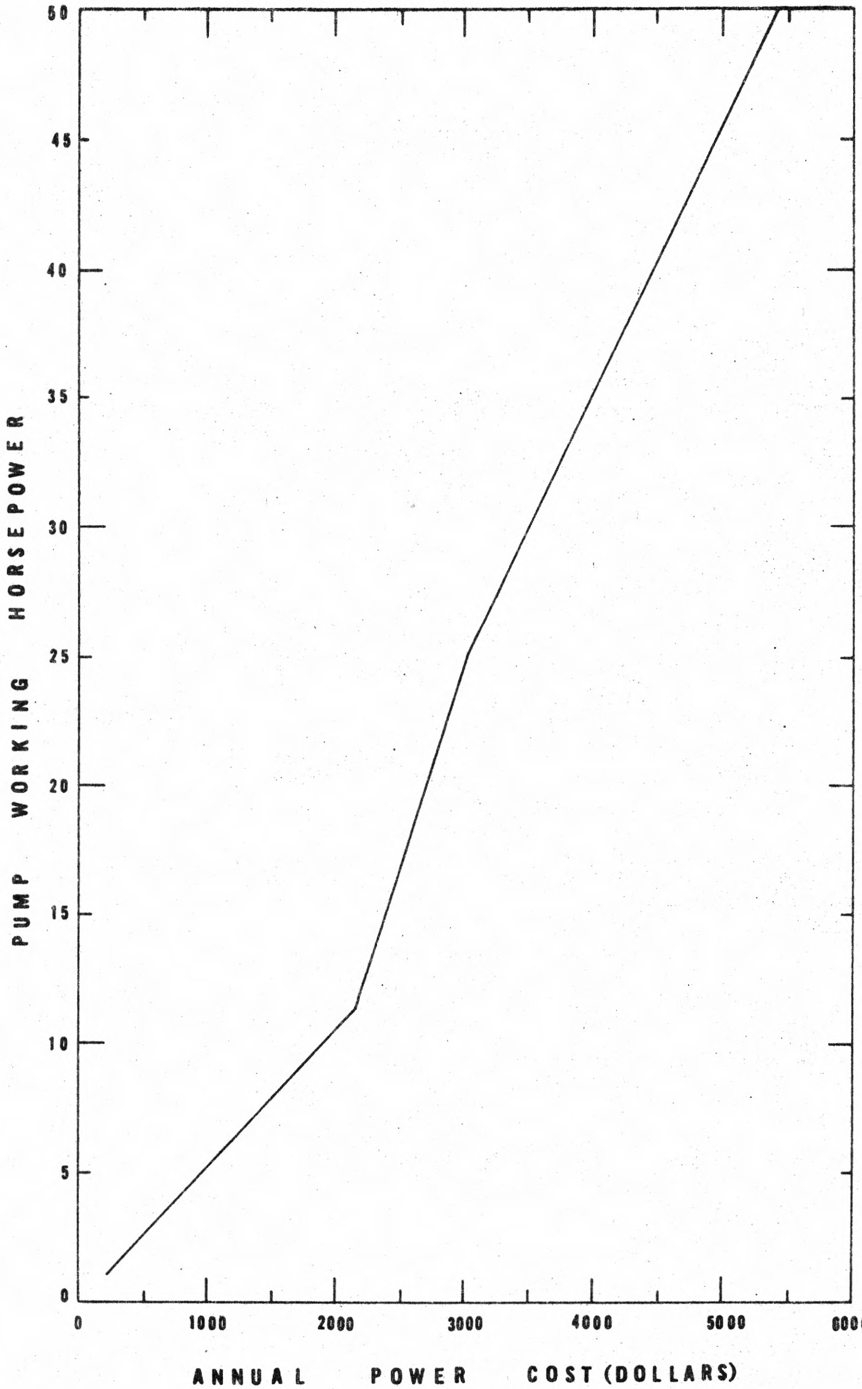

Figure 6. Graph showing the relation of annual power cost of pump working horsepower given in table 2, assuming a power demand of 24 hours a day.

12.--Annual maintenance costs

Annual maintenance costs were estimated from data obtained from the Pennsylvania Utility Commission and are here taken as 4 percent of the cost of the equipment given in column 4 of table 3. Over a period of 25 years, which is assumed to be the life of the equipment, this equals the cost given in column 4 and amounts to replacing the deep-well turbine unit once within the 25 years of assumed life of the equipment. In addition, 4 percent of $1,500 ($60) was added to the cost of screened wells, which allows for their redevelopment once in their 25-year life. No labor costs for operation were included. The well is assumed to be added to an existing distribution system and labor costs would not be great.

13.--Total annual cost

The total annual cost is the sum of the annual payments to retire the initial cost (column 10), the annual power costs (column 11), and the annual maintenance costs (column 12). It is again 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 delivering it to the consumer.

14.--Average annual cost to produce ground water in dollars per thousand gallons of design yield

This cost in dollars per thousand gallons is found by dividing the total annual cost (column 13, table 3) by the corresponding well yield in million gallons per year given in table 1. This result is divided by 1,000 to convert to cost per thousand gallons. The figures were reported to nearest tenth of a cent.

15.--Average annual cost to producer in dollars per million gallons per day of design yield

This cost in dollars per million gallons per day is found by dividing that total annual cost (column 13, table 3) by the production figure in million gallons per day given in table 1. The costs given in columns 14 and 15 are valid only for the design yield and only if all the assumptions given earlier are met. They are not valid for a specific site or situation except in the almost inconceivable instance where all the actual conditions equal all the assumptions made in the analysis. 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

Table 4 contains a summary of the water-quality characteristics of the geologic units. The values given in the table refer to the 75 percent (good), 50 percent (medium), and 25 percent (poor) categories for a normal frequency distribution of the reported values for each geologic unit for which chemical analyses were available. Because the values given in the table represent a range of only 50 percent of the available analyses, higher and lower values may occur in water from any particular well tapping a particular geologic unit. Although table 4 shows a range in concentration for any particular constituent in the water of each geologic unit, a single well will usually yield water of uniform quality throughout the year.

Table 5.--Cross reference of geologic units and water-service areas

A cross reference of geologic units and water-service areas is given in table 5. This table shows which aquifers are available to a given water-service area and how many water-service areas are potential users of a particular rock unit. A distinction is made in the table between (1) those geologic units that immediately underlie the water-service areas, and (2) those that do not, but are within 1 mile of the political boundaries of the water-service areas.

APPRAISAL BY GEOLOGIC UNIT

The geologic units listed in the tables and discussed in this section are those that are capable of yielding usable quantities of ground-water supplies to the water-service areas. All such geologic units listed as available to a water-service area either underlie or are within 1 mile of the political boundaries of that area. The names of the geologic formations or groups listed are those used by the U. S. Geological Survey. The symbols used to identify the formations are those shown on the Geologic Map of Pennsylvania (1960) published by the Pennsylvania Geologic Survey.

Formations or groups shown on the "Geologic Map of Pennsylvania" that are not discussed in this section are not "available to" the water-service areas for which specific information was requested (see fig. 1). The geologic units not discussed occupy only a small part of the Upper Susquehanna River basin in Pennsylvania, and generally are not considered to be potential aquifers for municipal, industrial, or irrigational use in any part of the upper basin.

The discussion by geologic units allows an evaluation of additional areas not specifically requested at this time. The units are discussed according to geologic age, from youngest to oldest. A short discussion of the grouping of geologic units shown on the geologic map is included where appropriate.

This discussion of water in each geologic unit includes sections on (1) availability, (2) quantity, (3) cost, and (4) quality.

(1) Availability--this section lists the availability of this geologic unit for those specific water-service areas requested. The listing of an area under a geologic unit implies that the unit occurs inside or within 1 mile of the boundaries of the area.

(2) Quantity--this section briefly discusses the quantity available for the 75 percent (poor), 50 percent (medium), and 25 percent (good) probability of occurrence of well yields for the aquifer in gallons per minute. The computed yields were rounded to the nearest 5 gpm for all yields under 100 gpm and to 2 significant figures above 100 gpm. Yields in excess of 1,000 gpm were reduced to 1,000 gpm.

(3) Cost--this section shows the average annual cost of water in dollars per million gallons per day for the 75 percent (poor), 50 percent (medium), and 25 percent (good) probability of occurrence of the design well yields. The costsin dollars were rounded to two significant figures. The costs in dollars per million gallons per day can be converted to dollars per cubic foot per second (cfs) by multiplying by 0.646.

(4) Quality--this section discusses briefly any quality problems known to occur in water from this geologic unit. Emphasis will be on dissolved solids, hardness, and iron content of the ground waters. The ranges discussed are only for the values given in table 4 between the 75 percent and 25 percent occurrence categories for a normal frequency distribution for the available analyses. Higher and lower values may occur in water from any particular well tapping this geologic unit. Where the high values may be particularly significant, they are also mentioned. In addition, data available for other constituents that exceed the Public Health Service standards in at least 25 percent of the samples are mentioned.

The terms low, moderate, and high are used in the text to describe the relative concentration of dissolved solids, hardness, and iron in accordance with the following concentration ranges chosen for the Susquehanna River basin.

	Dissolved solids (ppm)	Hardness (ppm)	Iron (ppm)
Low	0 - 150	0 - 100	0.0 - 0.3
Moderate	150 - 500	100 - 300	0.3 - 1.0
High	500	300	1.0

Quaternary Rocks

Holocene Alluvium

Some of the streams in the upper basin have built up slight flood plains during the Holocene Epoch, and locally such deposits may attain sufficient thickness to yield water to shallow wells. In general, Holocene alluvium is probably not present in sufficient thickness to be of importance as a source of ground water unless it functions as part of an aquifer unit consisting of the alluvium and the underlying Pleistocene sand and gravel. However, the alluvium does serve as a deposit through which recharge is transmitted to the underlying rocks, particularly the Pleistocene glacial deposits. The quality of the water is good to excellent in the alluvium, but may reflect the character of the adjacent stream if recharge from the stream is induced by pumping from the alluvium.

Pleistocene Deposits

The Pleistocene deposits are composed of glacial drift in the uplands, glacial lake and stream deposits in the valleys, and nonglacial stream deposits. The glacial drift in the uplands or interstream areas is usually less than 50 feet thick. This drift is composed largely of glacial debris or till that generally yields only small amounts of water. Larger supplies may be obtained from beds or lenses of sand and gravel, but these deposits are of limited or unknown extent and thickness. The most productive water-bearing materials in the upper basin are the gravels and sands laid down in glacial lakes and streams. Their known areal extent and local thickness are shown on figure 3. These deposits are not restricted to the areas covered by ice, but rather are restricted to valleys whose streams either carried away glacial flood waters or were dammed by the glaciers. The character of the lake sediments and glacial outwash differs considerably from place to place and may differ considerably within relatively short distances. The exact character, thickness, and distribution of these deposits will not be known until they are mapped in more detail. These deposits offer an excellent opportunity for artificial recharge and, hence, conjunctive use with surface water. Thick stream deposits of nonglacial origin occur in Cameron, Clinton, and southern Potter Counties. The major water-bearing Pleistocene deposits are the glacial lake and stream deposits shown on figure 3.

Availability

The Pleistocene sand and gravel deposits are available aquifers in the Sayre, Towanda, Emporium, Lock Haven, Renovo, Berwick, Bloomsburg, Scranton, Wilkes-Barre, Jersey Shore, Hughesville, Muncy, Williamsport, Danville, Milton, Susquehanna, Elkland, Mansfield, Wellsboro, Lewisburg, and Tunkhannock areas.

Quantity

Poor yield - 250 gpm
Medium yield - 540 gpm
Good yield - 1,200 gpm

Annual cost

For poor yield - $5,100 per mgd
For medium yield - $3,700 per mgd
For good yield - $2,500 per mgd

Quality

The water from the Pleistocene 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 contains low amounts of dissolved solids and hardness. 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. The high amounts of chloride appear to be related to the chloride content of the Devonian marine beds underlying the unconsolidated deposits.

Pennsylvanian Rocks

The rocks of Pennsylvanian age cropping out in the Plateau Province in the Upper Susquehanna basin include, in order of increasing age: the Conemaugh Formation (IPc), Allegheny Group (IPa), and Pottsville Formation (IPp). The correlative rocks in the Valley and Ridge Province of the Connemaugh and Allegheny of the Plateau are called post-Pottsville (IPpp) by the Pennsylvania Geological Survey and the Llewellyn Formation (IPl) by the U. S. Geological Survey. The Pennsylvanian rocks in the Plateau Province are flat lying, and in the Valley and Ridge Province they are steeply dipping. The Pennsylvanian rocks are composed of variable sequences of sandstone, shale, clay, limestone, and coal. The coal is classified as anthracite in the Valley and Ridge and bituminous in the Plateau. The Conemaugh and Pottsville contain several named members and the Allegheny contains several named formations, which have been mapped locally. Wells tapping sandstone members or formations will have higher yields than those tapping other rocks.

Llewellyn Formation (post-Pottsville)

The Llewellyn Formation (IPpp) is composed of brown or gray sandstone and shale containing some conglomerate and numerous minable coals. It occurs in the anthracite fields of the Valley and Ridge province.

Availability

The Llewellyn Formation (IPpp) is an available aquifer in the Scranton, Freeland, Hazelton, and Wilkes-Barre areas.

Quantity

Poor yield - 75 gpm
Medium yield - 230 gpm
Good yield - 760 gpm

Annual cost

For poor yield - $19,000 per mgd
For medium yield - $11,000 per mgd
For good yield - $6,900 per mgd

Quality

The water from the Llewellyn Formation is of excellent quality in places sufficiently far removed from mining operations. The water is low in dissolved solids, hardness, and iron. In parts of the northern coal field, as well as in most other fields, the water is generally unfit for ordinary use, because the oxidation of pyrite in the coal forms a highly acidic water that contains large quantities of iron.

Conemaugh Formation

The Conemaugh Formation (IPc) is composed of cyclic sequences of sandstone, red and gray shale, siltstone, limestone, and bituminous coal. Some commerical beds of bituminous coal are present. The Conemaugh strata generally have been drained and are above the zone of saturation in the vicinity of coal mines and where they form the caps of hills.

Availability

The Conemaugh Formation (IPc) is an available aquifer in the Barnesboro, Patton, Spangler, Philipsburg, Clearfield, Curwensville, Du Bois, Houtzdale, and Shawville areas.

Quantity

Poor yield - 145 gpm
Medium yield - 430 gpm
Good yield-1,000 gpm

Annual cost

For poor yield - $15,000 per mgd
For medium yield - $8,000 per mgd
For good yield - $5,600 per mgd

Quality

The water from the Conemaugh Formation is of good to excellent quality in places sufficiently far removed from mining operations. The water ranges from low to moderate in dissolved solids and hardness. The water is low in iron content. In the vicinity of mining operations the water may be unfit for ordinary use.

Allegheny Group

The Allegheny Group (IPa) is composed of cyclic sequences of sandstone, shale, limestone, and bituminous coal. The limestones thicken westward. The Allegheny Group contains many commercial coal beds. It includes the Vanport, Freeport, Kittanning, and Clarion Formations and the Brookville, Clarion, Kittanning, and Freeport coals. The Allegheny strata generally have been drained and are above the zone of saturation in the vicinity of coal mines.

Availability

The Allegheny Group is an available aquifer in the Barnesboro, Patton, Spangler, Philipsburg, Clearfield, Curwensville, DuBois, Houtzdale, Shawville, and Renovo areas.

Quantity

Poor yield - 125 gpm
Medium yield - 365 gpm
Good yield - 1,000 gpm

Annual cost

For poor yield - $16,000 per mgd
For medium yield - $8,500 per mgd
For good yield - $6,200 per mgd

Quality

The water from the Allegheny Group is of fair to excellent quality. The water ranges from low to moderate in dissolved solids and hardness. The water is low in iron content in places sufficiently far removed from mining operations. In areas close to active mines the water is usually acidic and high in iron. Even in some areas not affected by coal mining, the water may contain appreciable quantities of iron and hydrogen sulfide.

Pottsville Formation

The Pottsville Formation (IPp) is composed of coarse-grained sandstone, conglomerate, and some minable coal in the Valley and Ridge Province. In the Appalachian Plateau the Pottsville Formation is composed predominately of sandstone and conglomerate and contains thin beds of shale and coal. Some of the coals in the Plateau are mineable locally.

Availability

The Pottsville Formation is an available aquifer in the Appalachian Plateau Province in the Philipsburg, Clearfield, Curwensville, Shawville, and Renovo areas. The Pottsville Formation is an available aquifer in the Valley and Ridge Province in the Scranton, Freeland, Hazelton, and Wilkes-Barre areas. The Pottsville is a very productive aquifer in the Plateau where it lies below drainage level. Elsewhere, the Pottsville generally forms the highest capping of the Plateau and is probably drained near the bordering escarpments.

Quantity

	Appalachian Plateau	Valley and Ridge Province
Poor yield	135 gpm	120 gpm
Medium yield	560 gpm	240 gpm
Good yield	1,000 gpm	430 gpm

Annual cost

	Appalachian Plateau	Valley and Ridge Province
For poor yield	$15,000 per mgd	$16,000 per mgd
For medium yield	$ 7,300 per mgd	$11,000 per mgd
For good yield	$ 4,000 per mgd	$ 8,000 per mgd

Quality

The water from the Pottsville Formation in the Plateau is of poor to good quality for most uses. The water is low to moderate in dissolved solids and hardness. The iron content is high. In some places there is a considerable range in iron content of waters from different sandstones in the Pottsville, and if one bed yields water high in iron, it is sometimes possible to case-off the objectionable beds and find a water containing less iron in a deeper bed. A few wells yield water that contains hydrogen sulfide.

The water from the Pottsville Formation in the Valley and Ridge is generally of excellent quality. The water is low in dissolved solids, hardness, and iron. A few samples contain excess iron, are rather hard, and contain hydrogen sulfide.

Pennsylvanian and Mississippian Rocks

Mauch Chunk Formation

The Mauch Chunk Formation (Mmc) is composed of red shale and interbedded brown to greenish gray flaggy sandstone. The Mauch Chunk thins rapidly westward from its type locality and is absent over wide areas.

Availability

The Mauch Chunk Formation is an available aquifer in the Appalachian Plateau Province in the Philipsburg, Curwensville, and Renovo areas. The Mauch Chunk Formation is an available aquifer in the Valley and Ridge Province in the Scranton, Freeland, Hazelton, and Wilkes-Barre areas.

Quantity

	Entire area	Northern Anthracite field
Poor yield	45 gpm	45 gpm
Medium yield	100 gpm	75 gpm
Good yield	250 gpm	120 gpm

Annual cost

	Entire area	Northern Anthracite field
For poor yield	$24,000 mgd	$24,000 mgd
For medium yield	$18,000 mgd	$17,000 mgd
For good yield	$11,000 mgd	$16,000 mgd

Quality

The water from the Mauch Chunk Formation in the Plateau appears to be of poor quality for most uses. The water is high in total dissolved solids and iron content. The sulfate content is excessive. The hardness is moderate.

The water from the Mauch Chunk in the Valley and Ridge Province is of good quality for most uses. The water is low to moderate in dissolved solids, hardness, and iron. A few samples indicate high nitrate concentrations.

Mississippian Rocks

Pocono Formation

The Pocono Formation (Mp) is composed predominately of gray, hard, massive, cross-bedded conglomerate and sandstone and some shale beds.

Availability

The Pocono is an available aquifer in the Appalachian Plateau Province in the Emporium, Philipsburg, Curwensville, and Renovo areas. The Pocono is an available aquifer in the Valley and Ridge Province in the Scranton and Wilkes-Barre areas.

The Pocono in the Plateau is a very productive aquifer where it occurs below drainage level. The Pocono will probably not yield large supplies where it occurs as a cap rock on the plateaus owing to the drainage of ground water from this aquifer by springs along the edge of the plateaus.

Quantity

	Appalachian Plateau	Valley and Ridge Province
Poor yield	180 gpm	25 gpm
Medium yield	530 gpm	70 gpm
Good yield	1,000 gpm	220 gpm

Annual cost

	Appalachian Plateau	Valley and Ridge Province
For poor yield	$13,000 per mgd	$36,000 per mgd
For medium yield	$ 7,800 per mgd	$19,000 per mgd
For good yield	$ 5,000 per mgd	$11,000 per mgd

Quality

The water from the Pocono Formation is generally of very good quality, except for a high iron content. The dissolved-solids content ranges from low to moderate. The hardness is low. The iron content ranges from low to high and appears to be higher in the western part of the area. In the Appalachian Plateau the Pocono Formation contains saline water at depth.

Mississippian and Devonian Rocks

Susquehanna Group

The Susquehanna Group (Ds) is composed of sandstone and shale. The Susquehanna Group includes, in descending order: the Oswayo Formation, Catskill Formation, Chemung Formation, Trimmers Rock Sandstone, Brallier Shale, Harrell Shale, and Tully Limestone. On the 1960 edition of the Geologic Map of Pennsylvania, the Oswayo Formation is shown as Doo, the Catskill Formation as Dck, and the remaining section as marine beds (Dm). The rocks shown as Dm on the

1960 map are shown as the Chemung Formation (Dc) and the Portage Group (Dpg) on the 1932 edition of the Geologic Map of Pennsylvania. The entire Susquehanna Group is a gradational sequence in which formational contacts are established to a certain extent on predominance of one rock type over another. All the units occur in both the Appalachian Plateau and the Valley and Ridge Provinces, except the Oswayo which is mapped only in the Plateau.

Availability

The Susquehanna Group (Ds) is an available aquifer in the Appalachian Plateau Province in the Sayre, Towanda, Clarks Summit, Susquehanna, and Tunkhannock areas. The Susquehanna Group is an available aquifer in the Valley and Ridge Province in the Scranton, Wilkes-Barre, and Williamsport areas.

Quantity

	Appalachian Plateau	Valley and Ridge Province
Poor yield	35 gpm	25 gpm
Medium yield	110 gpm	60 gpm
Good yield	340 gpm	170 gpm

Annual cost

	Appalachian Plateau	Valley and Ridge Province
For poor yield	$29,000 per mgd	$34,000 per mgd
For medium yield	$16,000 per mgd	$21,000 per mgd
For good yield	$ 8,600 per mgd	$13,000 per mgd

Quality

The water from the Susquehanna Group is generally of good quality for most purposes. The dissolved solids and iron content and the hardness are discussed under each individual formation of the Susquehanna Group. The Susquehanna Group contains saline water at depth in the Appalachian Plateau.

Oswayo Formation

The Oswayo Formation (Doo) is composed of brownish and greenish gray, fine and medium grained sandstone and some shale and scattered calcareous lenses.

Availability

The Oswayo Formation is an available aquifer in the Appalachian Plateau Province in the Emporium and Renovo areas.

Quantity

Poor yield - 240 gpm
Medium yield - 340 gpm
Good yield - 500 gpm

Annual cost

For poor yield - $11,000 per mgd
For medium yield - $9,000 per mgd
For good yield - $7,900 per mgd

Quality

Water samples from the Oswayo Formation have not been analyzed chemically. The water is probably similar in quality to that in the Pocono Formation.

Catskill Formation

The Catskill Formation (Dck) is composed chiefly of red and brown shale and sandstone, but also contains gray sandstone and gray and greenish shale. The sandy continental Catskill grades into finer grained marine sediments in the western part of the basin.

Availability

The Catskill Formation is an available aquifer in the Appalachian Plateau Province in the Emporium, Renovo, Mansfield, and Wellsboro areas. The Catskill Formation is an available aquifer in the Valley and Ridge Province in the Scranton and Wilkes-Barre areas.

Quantity

	Appalachian Plateau	Valley and Ridge Province
Poor yield	40 gpm	20 gpm
Medium yield	125 gpm	55 gpm
Good yield	480 gpm	150 gpm

Annual cost

	Appalachian Plateau	Valley and Ridge Province
For poor yield	$24,000 per mgd	$42,000 per mgd
For medium yield	$16,000 per mgd	$21,000 per mgd
For good yield	$ 7,300 per mgd	$14,000 per mgd

Quality

The water from the Catskill Formation is generally of good to excellent quality for most purposes. The water from the Catskill in the Plateau ranges from low to moderate in dissolved solids and hardness. The water is low in iron content. However, the Catskill contains saline water at depth in the Plateau. The water from the Catskill in the Valley and Ridge ranges from low to moderate in dissolved-solids content. The water is low in iron content and hardness.

Devnoian Rocks

Marine beds

The Devonian marine beds (Dm) are composed of gray and olive brown shale, graywacke, sandstone, and a basal limestone unit. The sequence includes the Chemung Formation, Trimmers Rock Sandstone, Brallier Shale, Harrell Shale, and Tully Limestone. The Trimmers Rock, Brallier, and Harrell are shown on the 1932 edition of the Geologic Map of Pennsylvania as the Portage Group (Dpg)

Availability

The Devonian marine beds are available aquifers in the Appalachian Plateau Province in the Emporium, Elkland, Mansfield, and Wellsboro areas. The Devonian marine beds are available aquifers in the Valley and Ridge Province in the Lock Haven, Mill Hall, Berwick, Bloomsburg, Jersey Shore, Hughesville, Muncy, and Danville areas.

Quantity

	Appalachian Plateau	Valley and Ridge Province
Poor yield	30 gpm	25 gpm
Medium yield	85 gpm	50 gpm
Good yield	240 gpm	130 gpm

Annual cost

	Appalachian Plateau	Valley and Ridge Province
For poor yield	$29,000 per mgd	$34,000 per mgd
For medium yield	$17,000 per mgd	$22,000 per mgd
For good yield	$10,000 per mgd	$14,000 per mgd

Quality

Many of the wells tapping the Devonian marine beds produce water of fairly good quality. However, many of the wells in the Appalachian Plateau produce brackish or salty water high in sodium and chloride content. The water from the Devonian marine beds in the Appalachian Plateau ranges from low to high in dissolved-solids content and from low to moderate in iron content and hardness. In addition, many waters contain hydrogen sulfide, some contain considerable iron, and a few contain natural gas that can be ignited as it bubbles from the water. The water in the Devonian marine beds in the Valley and Ridge is of generally good quality for most uses. The water in the Valley and Ridge ranges from low to moderate in dissolved solids and hardness. The water is low in iron content.

Hamilton Group and Onondaga Limestone

The Hamilton Group (Dh) and Onondaga Limestone (Don) are composed of shale and limestone. The combined Hamilton Group and Onondaga Limestone are mapped as Dho. The Mahantango Formation of the Hamilton Group is mapped as Dmh. The Marcellus Shale of the Hamilton Group, and the underlying Onondaga Limestone are combined and indicated by Dmo.

Availability

The Hamilton Group and Onondaga Limestone are available aquifers in the Valley and Ridge Province in the Lock Haven, Mill Hall, Berwick, Bloomsburg, Jersey Shore, Hughesville, Muncy, Williamsport, Danville, Milton, and Lewisburg areas.

Quantity

Poor yield - 45 gpm
Medium yield - 110 gpm
Good yield - 250 gpm

Annual cost

For poor yield - $23,000 per mgd
For medium yield - $16,000 per mgd
For good yield - $10,000 per mgd

Quality

The water from these rocks is of generally good quality for most uses. The water contains low to moderate amounts of dissolved solids and hardness. The iron content ranges from low to high. Hydrogen sulfide has been reported in water from several wells in each formation.

Oriskany Group

The Oriskany Group (Do) is composed of sandstone, limestone, and shale. The Oriskany Group is composed of the Ridgeley Sandstone and the Shriver Chert. The combined Oriskany Group and underlying Helderberg Limestone are indicated by Doh.

Availability

The Oriskany Group is an available aquifer in the Valley and Ridge Province in the Lock Haven, Mill Hall, Bloomsburg, Jersey Shore, Muncy, Williamsport, Danville, Milton, and Lewisburg areas.

Quantity

Poor yield - 290 gpm
Medium yield - 420 gpm
Good yield - 620 gpm

Annual cost

For poor yield - $9,900 per mgd
For medium yield - $8,100 per mgd
For good yield - $7,200 per mgd

Quality

The water from the Oriskany Group is of good to excellent quality for most uses. The water contains low to moderate amounts of dissolved solids, hardness, and iron.

Helderberg Limestone

The Helderberg Limestone (Dhb) is composed of shale and limestone. The combined Oriskany Group and Helderberg Limestone are indicated by Doh.

Availability

The Helderberg Limestone is an available aquifer in the Valley and Ridge Province in the Lock Haven, Mill Hall, Bloomsburg, Jersey Shore, Muncy, Williamsport, Danville, Milton, and Lewisburg areas.

Quantity

Poor yield - 35 gpm
Medium yield - 140 gpm
Good yield - 600 gpm

Annual cost

For poor yield - $21,000 per mgd
For medium yield - $10,000 per mgd
For good yield - $5,000 per mgd

Quality

Water from the Helderberg Limestone is of fairly good quality. The water contains a moderate amount of dissolved solids and a moderate to high amount of hardness. The iron content is low. A few samples indicate a dissolved-solids content that is too high for most industrial uses, and some of the water is unfit for practically any use except cooling. These waters have a high dissolved-solids content containing large amounts of calcium sulfate.

Devonian and Silurian Rocks

Keyser and Tonoloway Limestones

The Keyser and Tonoloway Limestones are predominately limestones. The combined Keyser and Tonoloway Limestones are indicated by Skt. The combined Keyser and Tonoloway Limestones and the underlying Wills Creek Shale are indicated by Skw. The undifferentiated Keyser, Tonoloway, Wills Creek, Bloomsburg, and McKenzie Formations are indicated by Skm.

Availability

The Keyser and Tonoloway Limestones are available aquifers in the Valley and Ridge Province in the Bellefonte, Lock Haven, Mill Hall, Berwick, Bloomsburg, Jersey Shore, Muncy, Williamsport, Danville, Milton, and Lewisburg areas.

Quantity

Poor yield - 50 gpm
Medium yield - 230 gpm
Good yield - 1,000 gpm

Annual cost

For poor yield - $16,000 per mgd
For medium yield - $7,800 per mgd
For good yield - $3,400 per mgd

Quality

The water from the Keyser and Tonoloway Limestones is of fairly good quality for most uses. The water contains a moderate amount of dissolved solids and hardness. The iron content is low. A few samples have high nitrate concentrations. A few wells yield water that contains large amounts of calcium, sulfate, and iron. Some of this water is too hard for many industrial uses and is unfit for practically any use except cooling.

Silurian Rocks

Wills Creek Shale, Bloomsburg Shale, and McKenzie Formation

The Wills Creek Shale (Sw) is a greenish-gray shale containing some beds of limestone and sandstone. The Bloomsburg Shale is predominately a red siltstone and shale containing some beds of sandstone and limestone. The McKenzie Formation is predominately a greenish-gray shale containing some thin limestones and red shale. The combined Keyser, Tonoloway, and Wills Creek Formations are indicated by Skw. The combined Bloomsburg and McKenzie Formations are indicated by Sbm. The combined Wills Creek, Bloomsburg, and McKenzie Formations are indicated by Swm. The undifferentiated Keyser, Tonoloway, Wills Creek, Bloomsburg, and McKenzie Formations are indicated by Skm.

Availability

The Wills Creek, Bloomsburg, and McKenzie Formations are available aquifers in the Valley and Ridge Province, in the Bellefonte, Lock Haven, Mill Hall, Berwick, Bloomsburg, Jersey Shore, Muncy, Williamsport, Danville, Milton, and Lewisburg areas.

Quantity

Poor yield - 30 gpm
Medium yield - 85 gpm
Good yield - 200 gpm

Annual cost

For poor yield - $30,000 per mgd
For medium yield - $17,000 per mgd
For good yield - $12,000 per mgd

Quality

The water from these rocks is of fairly good quality for most purposes. The water contains a moderate amount of dissolved solids, low to moderate amounts of hardness, and a low iron content. A few wells yield water that contains large amounts of calcium sulfate. Some of this water is unfit for practically any use except cooling. The wells tapping the Bloomsburg Shale will probably obtain fairly soft water, but almost any other formation in this group of rocks, particularly the Wills Creek Shale, generally yield hard water containing calcium sulfate derived from gypsum or anhydrite in the rock.

Clinton Group

The Clinton Group is composed chiefly of gray and greenish sandstone and shale and a small proportion of limestone and red sandstone. The Clinton Group is indicated by Sc and includes in order of descending age: The Rochester Shale, Keefer Sandstone, and Rose Hill Formation.

Availability

The Clinton Group is an available aquifer in the Valley and Ridge Province in the Bellefonte, Lock Haven, Mill Hall, Bloomsburg, Jersey Shore, Muncy, Williamsport, and Danville areas.

Quantity

Poor yield - 30 gpm
Medium yield - 70 gpm
Good yield - 150 gpm

Annual cost

For poor yield - $30,000 per mgd
For medium yield - $19,000 per mgd
For good yield - $14,000 per mgd

Quality

The water from the Clinton Group is of good quality for most uses. The water contains a low amount of dissolved solids and hardness. The iron content ranges from low to moderate. One deep well sample contained water with a dissolved-solids content greater than 2,300 ppm, most of which was sodium chloride.

Tuscarora Quartzite

The Tuscarora Quartzite (St) is a fine-grained quartzitic sandstone that is conglomeratic in part. The Tuscarora Quartzite is unimportant as a source of ground water, owing to its topographic position on the summits of the highest ridges. The Tuscarora is an available aquifer in the Valley and Ridge Province in the Bellefonte, Lock Haven, Mill Hall, Williamsport, and Danville areas. Several springs along the talus slopes of the Tuscarora yield very soft water that is low in dissolved solids and of excellent quality.

Ordovician Rocks

Juniata Formation and Oswego Sandstone

The Juniata Formation (Oj) is a red quartzite interbedded with red shale. The Oswego Sandstone (Obe), named the Bald Eagle Formation by the Pennsylvania Geological Survey, is a greenish-gray sandstone interbedded with greenish-gray shale. The combined Juniata Formation and Oswego Sandstone are indicated by Ojb.

Availability

The Juniata and Oswego Formations are available aquifers in the Valley and Ridge Province in the Bellefonte and Mill Hall areas.

Quantity

Poor yield - 20 gpm
Medium yield - 30 gpm
Good yield - 60 gpm

Annual cost

For poor yield - $40,000 per mgd
For medium yield - $30,000 per mgd
For good yield - $20,000 per mgd

Quality

The water from these formations is of excellent quality for most uses. The water contains a low amount of dissolved solids, hardness, and iron.

Reedsville Shale

The Reedsville Shale (Or) is a gray shale containing silty and sandy interbeds. The Reedsville is the central Pennsylvania equivalent of the Martinsburg Shale.

Availability

The Reedsville Shale is an available aquifer in the Valley and Ridge Province in the Bellefonte and Mill Hall areas.

Quantity

Poor yield - 20 gpm
Medium yield - 30 gpm
Good yield - 50 gpm

Annual cost

For poor yield - $38,000 per mgd
For medium yield - $30,000 per mgd
For good yield - $21,000 per mgd

Quality

The water from the Reedsville Shale is of fairly good quality for most uses. The water contains a low to moderate amount of dissolved solids, hardness, and iron. A few samples contain high amounts of iron and nitrate and small quantities of hydrogen sulfide.

Middle Ordovician Limestones

The Middle Ordovician rocks are composed almost entirely of calcium and magnesium limestones. They contain the Trenton Limestone, the Black River Group (which includes the Rodman Limestone, the Lowville Limestone, and the equivalent Chambersburg Limestone), and the Coburn Limestone and the equivalent St. Paul Group. On the Geologic Map of Pennsylvania (1960) these units are shown as the Coburn, Salona, and Nealmont Formations indicated by Ocn; and the Curtin, Benner, Hatter, and Loysburg Formations indicated by Ovl. The entire section is also shown on the Geologic Map of Pennsylvania as Ocl.

Availability

The Middle Ordovician rocks are available aquifers in the Valley and Ridge Province in the Bellefonte and State College areas.

Quantity

Poor yield - 40 gpm
Medium yield - 130 gpm
Good yield - 420 gpm

Annual cost

For poor yield - $19,000 per mgd
For medium yield - $10,000 per mgd
For good yield - $6,000 per mgd

Quality

The water from these rocks does not appear to be typical limestone water. It is of excellent quality for most uses as it contains low amounts of dissolved solids, hardness, and iron. A few samples have high nitrate concentrations.

Beekmantown Group

The Beekmantown Group (Ob) is composed of interbedded limestone and dolomite and some cherty layers. The Beekmantown consists of the Bellefonte Dolomite (Obf), Axemann Formation (Oa), Nittany Formation (On), Stonehenge Limestone (Os), and Larke Dolomite (Os). The U.S. Geological Survey includes the Mines Dolomite (Ꞓm) in the Beekmantown Group, whereas the Pennsylvania Geological Survey considers the Mines Formation to be of Cambrian age. In this report it has been included with the Cambrian rocks. The combined Bellefonte and Axemann Formations are shown on the Geologic Map of Pennsylvania as Oba, and the combined Nittany, Stonehenge, and Larke Formations as Ons.

Availability

The Beekmantown Group is an available aquifer in the Valley and River Province in the Bellefonte and State College areas.

Quantity

Poor yield - 60 gpm
Medium yield - 480 gpm
Good yield - 1,000 gpm

Annual cost

For poor yield - $14,000 per mgd
For medium yield - $5,400 per mgd
For good yield - $3,000 per mgd

Quality

The water from the Beekmantown Group is typical limestone water of fairly good quality. The water contains a moderate amount of dissolved solids and hardness. The iron content is low. A few samples indicate high nitrate concentrations.

Ordovician and Cambrian Rocks

Mines Dolomite and Gatesburg Formation

The Mines Dolomite (Ꞓm) is a dolomite containing much chert and the Gatesburg Formation (Ꞓg) is a dolomite containing many interbedded sandstones. The combined formations are shown on the map as Ꞓmg. The U. S. Geological Survey considers the Mines Dolomite to be of Ordovician age and to be in the Beekmantown Group, whereas the Pennsylvania Geological Survey considers it to be of Cambrian age, and not a part of the Beekmantown.

Availability

The Mines Dolomite and Gatesburg Formation are available aquifers in the Valley and Ridge Province in the Bellefonte and State College areas.

Quantity

Poor yield - 110 gpm
Medium yield - 240 gpm
Good yield - 520 gpm

Annual cost

For poor yield - $11,000 per mgd
For medium yield - $7,500 per mgd
For good yield - $5,400 per mgd

Quality

The water from the Mines and Gatesburg is typical limestone water of fairly good quality. The water contains a low to moderate amount of dissolved solids and a moderate amount of hardness. The iron content is generally low. A few samples have a high nitrate content.

Warrior Limestone

The Warrior Limestone (Ꞓw) is a bluish-gray fine-grained dolomite containing some thin shale layers. The Warrior Limestone is potentially a moderately productive aquifer in the Valley and Ridge Province, but it has not been utilized extensively, except as a source of water for domestic use. Insufficient data are available for a detailed analysis of its water-bearing properties, although the unit is a potential aquifer in the Williamsburg area. The water quality probably is similar to that in other typical limestone aquifers.

APPRAISAL BY AREA

The water-service areas within the Upper Susquehanna River basin in Pennsylvania selected for study by the U. S. Public Health Service and concurred on by the U. S. Army Corps of Engineers, are shown in figure 1. These areas are considered to be the nuclei around which future population growth in the Upper Susquehanna basin will occur. Most of them have a population in excess of 5,000 according to the 1960 Bureau of Census Report, but a few smaller areas are listed because these Federal agencies were specifically concerned about the availability of ground water for use as a source for public water supply. The areas are discussed by county, in alphabetical order. All the corporate units (municipality or township) included within each water-service area are not listed in the text but generally include these corporate units surrounding the nucleus city or town. The geologic units listed as being available occur either inside of or within 1 mile of the boundaries of the areas under discussion.

For the consolidated rock aquifers, the exact location of the geologic unit may be found by referring to the Geologic Map of Pennsylvania (1960). The unconsolidated glacial deposits are shown on figure 3. The aquifers available to each local municipal area may be compared as to yield, cost, and quality of ground water by reference to tables 1, 2, 3, and 4 and to the section on appraisal by geologic units. A cross reference of geologic units and the water-service areas to which they are available are given in table 5.

In appraising and evaluating various geologic units available to a local municipal area, a tabulation of ground-water yields, costs, and chemical quality by aquifer should be made. This tabulation would assist the water resources planner or manager to select the most promising aquifers for ground-water development. Such a tabulation was not made because it would have been duplication of work presented elsewhere in the report.

Bradford County, Pa.

Sayre Area

The available aquifers in the Sayre area are the Pleistocene sand and gravel deposits and the Susquehanna Group (Ds). On the 1932 edition of the Geologic Map of Pennsylvania, the bedrock underlying Sayre is shown as the Chemung Formation. Both aquifers underlie the Borough of Sayre.

Towanda Area

The available aquifers in the Towanda area are the Pleistocene sand and gravel deposits and the Susquehanna Group (Ds). On the 1932 edition of the Geologic Map of Pennsylvania, the bedrock underlying Towanda is shown as the Chemung Formation. Both aquifers underlie the Borough of Towanda.

Cambria County, Pa.

Barnesboro Area

The available aquifers in the Barnesboro area are the Conemaugh Formation (IPc) and the Allegheny Group (IPa). Both aquifers underlie the Borough of Barnesboro.

Patton Area

The available aquifers in the Patton area are the Conemaugh Formation (IPc) and the Allegheny Group (IPa). Both aquifers underlie the Borough of Patton.

Spangler Area

The available aquifers in the Spangler area are the Conemaugh Formation (IPc) and the Allegheny Group (IPa). Both aquifers underlie the Borough of Spangler.

Cameron County, Pa.

Emporium Area

The available aquifers in the Emporium area are: the Pleistocene sand and gravel deposits, the Pocono Formation (Mp), the Oswayo Formation (Doo), the Catskill Formation (Dck), and the Devonian marine beds (Dm). The Pleistocene sand and gravel deposits, Catskill Formation, and Devonian marine beds underlie the Borough of Emporium.

Carbon County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Carbon County.

Centre County, Pa.

Bellefonte Area

The available aquifers in the Bellefonte area are: the combined Keyser, Tonoloway, Wills Creek, Bloomsburg, and McKenzie Formations (Skm), the Clinton Group (Sc), the Tuscarora Quartzite (St), the Juniata Formation (Oj), the Osewego Sandstone (Obe), the Reedsville Shale (Or), the Middle Ordovician Limestones (Ov, Ocl), the Beekmantown Group (Ob, Oba, On, Os), the Mines Dolomite (Єm), and the Gatesburg Formation (Єg). The Middle Ordovician Limestones and the Beekmantown Group underlie the Borough of Bellefonte.

Philipsburg Area

The available aquifers in the Philipsburg area are: Conemaugh Formation (₱c), the Allegheny Group (₱a), the Pottsville Formation (₱p), the Mauch Chunk Formation (Mmc), and the Pocono Formation (Mp). The Allegheny Group underlies the Borough of Philipsburg.

State College Area

The available aquifers in the State College area are: the Middle Ordovician Limestones (Ocl, Ovn), the Beekmantown Group (Os, On, Oa, Obf), the Mines Dolomite (Єm), and the Gatesburg (Єg) Formation. The Beekmantown Group underlies the Borough of State College.

Clearfield County, Pa.

Clearfield Area

The available aquifers in the Clearfield area are: the Conemaugh Formation (₱c), the Allegheny Group (₱a), and the Pottsville Formation (₱p). The Allegheny Group and Pottsville Formation underlie the Borough of Clearfield.

Curwensville Area

The available aquifers in the Curwensville area are: the Conemaugh Formation (ℙc), the Allegheny Group (ℙa), the Pottsville Formation (ℙp), the Mauch Chunk Formation (Mmc), and the Pocono Formation (Mp). The Allegheny Group and Pottsville Formation underlie the Borough of Curwensville.

Du Bois Area

The available aquifers in the Du Bois area are the Conemaugh Formation (ℙc) and the Allegheny Group (ℙa). The Conemaugh Formation underlies the City of Du Bois.

Houtzdale Area

The available aquifers in the Houtzdale area are the Conemaugh Formation (ℙc) and the Allegheny Group (ℙa). Both aquifers underlie the Borough of Houtzdale.

Shawville Area

The available aquifers in the Shawville area are: the Conemaugh Formation (ℙc), and the Allegheny Group (ℙa), and the Pottsville Formation (ℙp). The Pottsville Formation underlies the Borough of Shawville.

Clinton County, Pa.

Lock Haven Area

The available aquifers in the Lock Haven area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones, Wills Creek and Bloomsburg Shales, and McKenzie Formation (Skm), the Clinton Group (Sc), and the Tuscarora Quartzite (St). The Devonian marine beds, Clinton Group, and Tuscarora Quartzite are the only available aquifers that do not underlie the Borough of Lock Haven.

Mill Hall Area

The available aquifers in the Mill Hall area are: the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones, Wills Creek and Bloomsburg Shales, and McKenzie Formation (Skm), the Clinton Group (Sc), Tuscarora

Quartzite (St), Juniata Formation (Oj), Oswego Sandstone (Obe), and Reedsville Shale (Or). The Keyser, Tonoloway, Wills Creek, Bloomsburg, McKenzie, and Tuscarora Formations and the Clinton Group underlie the Borough of Mill Hall.

Renovo Area

The available aquifers in the Renovo area are: the Pleistocene sand and gravel deposits, the Allegheny Group (IPa), the Pottsville Formation (IPp), the Mauch Chunk Formation (Mmc), the Pocono Formation (Mp), the Oswayo Formation (Doo), and the Catskill Formation (Dck). The Oswayo and Catskill Formations underlie the Borough of Renovo.

Columbia County, Pa.

Berwick Area

The available aquifers in the Berwick area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Keyser and Tonoloway Limestones and Wills Creek Shale (Skw), and the combined Bloomsburg Shale and McKenzie Formation (Sbm). The Pleistocene glacial deposits and the Keyser, Tonoloway, Wills Creek, Bloomsburg, and McKenzie Formations underlie the Borough of Berwick.

Bloomsburg Area

The available aquifers in the Bloomsburg area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones and Wills Creek Shale (Skw), the combined Bloomsburg Shale and McKenzie Formation (Sbm), and the Clinton Group (Sc). The Devonian marine beds are the only aquifers that do not underlie the Borough of Bloomsburg.

Elk County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Elk County.

Jefferson County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Jefferson County.

Indiana County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Indiana County.

Lackawanna County, Pa.

Clarks Summit Area

The available aquifer in the Clarks Summit area is the Susquehanna Group (Ds) which underlies the entire Borough of Clarks Summit. The bedrock is most likely the Catskill Formation (Dck).

Scranton Area

The available aquifers in the Scranton area are: the Pleistocene sand and gravel deposits, the Llewellyn Formation (IPpp), the Pottsville Formation (IPp), the Mauch Chunk Formation (Mmc), the Pocono Formation (Mp), the Susquehanna Group (Ds), and the Catskill Formation (Dck). The Pleistocene sand and gravel deposits and the Llewellyn and Pottsville Formations underlie the City of Scranton.

Luzerne County, Pa.

Freeland Area

The available aquifers in the Freeland area are: the Llewellyn Formation (IPpp), the Pottsville Formation (IPp), and the Mauch Chunk Shale (Mmc). All of the available aquifers underlie the Borough of Freeland.

Hazelton Area

The available aquifers in the Hazelton area are: the Llewellyn Formation (IPpp), the Pottsville Formation (IPp), and the Mauch Chunk Shale (Mmc). All of the available aquifers underlie the City of Hazelton.

Wilkes-Barre Area

The available aquifers in the Wilkes-Barre area are: the Pleistocene sand and gravel deposits, the Llewellyn Formation (IPpp), the Pottsville Formation (IPp), the Mauch Chunk Shale (Mmc), Pocono Formation (Mp), the Susquehanna Group (Ds), and the Catskill Formation (Dck). The Pleistocene glacial deposits and the Llewellyn Formation underlie the City of Wilkes-Barre.

Lycoming County, Pa.

Jersey Shore Area

The available aquifers in the Jersey Shore area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones, Wills Creek and Bloomsburg Shales, and McKenzie Formation (Skm), and the Clinton Group (Sc). The Clinton Group is the only available aquifer that does not underlie the Borough of Jersey Shore.

Hughesville Area

The available aquifers in the Hughesville area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), and the combined Hamilton Group and Onondaga Limestone (Dho). All of the available aquifers underlie the Borough of Hughesville.

Muncy Area

The available aquifers in the Muncy area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones, Wills Creek and Bloomsburg Shales, and McKenzie Formation (Skm), and the Clinton Group (Sc). The Devonian marine beds and Clinton Group are the only available aquifers that do not underlie the Borough of Muncy.

Williamsport Area

The available aquifers in the Williamsport area are: the Pleistocene sand and gravel deposits, the Susquehanna Group (Ds), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones, Wills Creek and Bloomsburg Shales, and McKenzie Formation (Skm), the Clinton Group (Sc), and the Tuscarora Quartzite (St). The Clinton Group and Tuscarora Quartzite are the only available aquifers that do not underlie the City of Williamsport.

McKean County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of McKean County.

Montour County, Pa.

Danville Area

The available aquifers in the Danville area are: the Pleistocene sand and gravel deposits, the Devonian marine beds (Dm), the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones and Wills Creek Shale (Skw), the combined Bloomsburg Shale and McKenzie Formation (Sbm), the Clinton Group (Sc), and the Tuscarora Quartzite (St). The Devonian marine beds, Clinton Group, and Tuscarora Quartzite are the only available aquifers that do not underlie the Borough of Danville.

Northumberland County, Pa.

Milton Area

The available aquifers in the Milton area are: the Pleistocene sand and gravel deposits, the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Don), the combined Keyser and Tonoloway Limestones and Wills Creek Shale (Skw), the combined Bloomsburg Shale and McKenzie Formation (Sbm). The Keyser, Tonoloway, Wills Creek, Bloomsburg, and McKenzie Formations underlie the Borough of Milton.

Potter County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Potter County.

Susquehanna County, Pa.

Susquehanna Area

The available aquifers in the Susquehanna area are the Pleistocene sand and gravel deposits and the Susquehanna Group (Ds). Both of the available aquifers underlie the Borough of Susquehanna. The Devonian bedrock is likely to be the Chemung Formation in the valley area and the Catskill Formation in the surrounding hills as shown on the 1932 edition of the Geologic Map of Pennsylvania.

Tioga County, Pa.

Elkland Area

The available aquifers in the Elkland area are the Pleistocene sand and gravel deposits and the Devonian marine beds (Dm). Both of the available aquifers underlie the Borough of Elkland.

Mansfield Area

The available aquifers in the Mansfield area are: the Pleistocene sand and gravel deposits, the Catskill Formation (Dck), and the Devonian marine beds (Dm). The Pleistocene sand and gravel deposits and the Devonian marine beds underlie the Borough of Mansfield.

Wellsboro Area

The available aquifers in the Wellsboro area are: the Pleistocene sand and gravel deposits, the Catskill Formation (Dck), and the Devonian marine beds (Dm). The Pleistocene sand and gravel deposits and the Devonian marine beds underlie the Borough of Wellsboro.

Union County, Pa.

Lewisburg Area

The available aquifers in the Lewisburg area are: the Pleistocene sand and gravel deposits, the combined Hamilton Group and Onondaga Limestone (Dho), the combined Oriskany Group and Helderberg Limestone (Doh), the combined Keyser and Tonoloway Limestones and Wills Creek Shale (Skw), and the combined Bloomsburg Shale and McKenzie Formation (Sbm). The Pleistocene sand and gravel deposits, the Oriskany Group and the Helderberg, Keyser, Tonoloway, and Wills Creek Formations underlie the Borough of Lewisburg.

Wayne County, Pa.

No designated water-service area occurs within the Upper Susquehanna River basin part of Wayne County.

Wyoming County, Pa.

Tunkhannock Area

The available aquifers in the Tunkhannock Area are the Pleistocene sand and gravel deposits and the Susquehanna Group (Ds). Both of the available aquifers underlie the Borough of Tunkhannock. The Devonian bedrock is likely to be the Catskill Formation as shown on the 1932 edition of the Geologic Map of Pennsylvania.

REFERENCES CITED

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. Detailed reports by Stanley W. Lohman (1937, 1938, and 1939) on ground water in northeastern, south-central, and north-central Pennsylvania contain a detailed description, including well records, of the geology and ground-water resources of the entire drainage basin of the Upper Susquehanna River basin in Pennsylvania. Lohman's reports were prepared under a cooperative program between the U.S. Geological Survey and the Pennsylvania Topographic and Geologic Survey. Lohman's reports contain the bulk of the data used in this report. This report would not have been possible to prepare in its present form without the background material available as the result of the past cooperative program between the Federal and State Surveys. These reports make it unnecessary to list a lengthy bibliography that provides a general description of the geography, geology, and hydrology of the basin.

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Table 1.--Estimated specific capacities and yields of hypothetical wells in the geologic units of the upper Susquehanna River basin in Pennsylvania

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 for 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 text and tables 2 and 3.

Geologic unit (Formation or Group)	Geologic age	Symbol on Geologic Map of Pennsylvania (1960 Ed.) scale 1:250,000	Area in which well analyses are valid	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)		
				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
Sand and gravel	Pleistocene	--------	Entire area	8.3	18	40	28	< 2	250	0.36	130	540	0.78	280	1,200	1.7	630
Conemaugh and Allegheny	Pennsyl-vanian	IPc	Plateau	.88	2.6	7.8	25	< 2	145	.21	76	430	.62	230	1,000	1.4	530
		IPa							125	.18	66	365	.53	191	1,000	1.4	530
Post-Pottsville	Pennsyl-vanian	IPpp	Valley and Ridge	.41	1.3	4.2	5	< 2	75	.11	39	230	.33	120	760	1.1	400
Pottsville	Pennsyl-vanian	IPp	Plateau	.80	3.3	14	24	< 2	135	.19	71	560	.81	294	1,000	1.4	530
			Valley and Ridge	.70	1.4	2.5	4	< 2	120	.17	63	240	.35	130	430	.62	230
Mauch Chunk	Mississip-pian	Mmc	Northern anthracite field	.25	.41	.68	8	< 2	45	.065	24	75	.11	39	120	.17	63
			Entire area	.26	.56	1.40	12	< 2	45	.065	24	100	.14	53	250	.36	130
Pocono	Mississip-pian	Mp	Plateau	1.10	3.3	10	47	< 2	180	.26	95	530	.76	278	1,000	1.4	530
			Valley and Ridge	.13	.40	1.2	8	11	25	.036	13	70	.10	37	220	.32	120
Susquehanna Group	Devonian and Mississippian	Ds	Plateau	.22	.68	2.2	118	11	35	.050	18	110	.16	58	340	.49	180
			Valley and Ridge	.14	.33	.96	61	22	25	.036	13	60	.086	32	170	.24	88
Oswayo	Devonian	Doo	Plateau	1.5	2.1	3.1	5	< 2	240	.35	130	340	.49	180	500	.72	260
Catskill	Devonian and Mississippian	Dck	Plateau	.26	.84	3.2	70	12	40	.06	21	125	.18	66	480	.69	250
			Valley and Ridge	.14	.34	.96	35	20	20	.029	11	55	.079	29	150	.22	80
Marine beds	Devonian	Dm	Plateau	.19	.50	1.4	46	10	30	.043	16	85	.12	45	240	.35	130
			Valley and Ridge	.13	.30	.74	26	19	25	.036	13	50	.075	27	130	.19	68
Hamilton and Onondaga	Devonian	Dho, Dh, Dmh, Don, Dmo	Valley and Ridge	.26	.60	1.4	29	3	45	.065	24	110	.16	58	250	.36	130
Oriskany	Devonian	Doh, Do	Valley and Ridge	1.8	2.6	3.9	8	< 2	290	.42	150	420	.60	220	620	.89	330
Helderberg	Devonian	Doh, Dhb	Valley and Ridge	.62	2.3	10	9	18	35	.050	18	140	.20	74	600	.86	320
Keyser and Tonoloway	Devonian and Silurian	Skm, Skw, Skt	Valley and Ridge	.62	2.9	18	22	26	50	.072	26	230	.33	120	1,000	1.4	530
Wills Creek, Bloomsburg, and McKenzie	Silurian	Skm, Swm, Sw, Sbm	Valley and Ridge	.16	.46	1.1	27	6	30	.043	16	85	.12	45	200	.29	110
Clinton	Silurian	Sc	Valley and Ridge	.18	.38	.85	13	6	30	.043	16	70	.10	37	150	.22	79
Juniata and Oswego	Ordovician	Oj, Obe, Ojb	Valley and Ridge	.11	.19	.36	6	10	20	.029	11	30	.043	16	60	.086	32
Reedsville	Ordovician	Or	Valley and Ridge	.12	.18	.29	5	4	20	.029	11	30	.043	16	50	.072	26
Middle Ordovician limestones	Ordovician	Ocl, Ocn, Ovl, Ov	Valley and Ridge	.60	1.8	5.8	6	10	40	.058	21	130	.19	68	420	.60	220
Beekmantown	Ordovician	Ob, Ons, Oba, Obf, Oa, Cn, Os	Valley and Ridge	1.0	8.0	72	13	18	60	.086	32	480	.69	250	1,000	1.4	530
Mines and Gatesburg	Ordovician and Cambrian	Єm, Єma, Єg	Valley and Ridge	2.7	6.0	13	18	< 2	110	.16	58	240	.35	130	520	.75	270

Table 2.--Well design of hypothetical wells in the geologic units of the upper Susquehanna River basin in Pennsylvania

Well diameter: Chosen according to pump diameter, which is based on yields given in table 1; 0 to 100 gallons per minute, 4-inch pump, 6-inch well; 100 to 250 gallons per minute, 6-inch pump, 8-inch well; 250 to 500 gallons per minute, 8-inch pump, 10-inch well; 500 to 1,000 gallons per minute, 10-inch pump, 12-inch well; 1,000 gallons per minute, 12-inch pump, 14-inch well
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 cost.
Water delivered to the land surface at zero pressure.

Geologic unit (Formation or Group)	Area in which well analyses are valid	Well depth (feet)	Well diameter (inches)			Length of casing (feet)	Static water level (feet below land surface)	Pumping water level (feet below land surface)		Drawdown (pumping water level minus static water level) (feet)		Pump working horsepower		
			For poor yield	For medium yield	For good yield			For poor and medium yields	For good yield	For poor and medium yields	For good yield	For poor yield	For medium yield	For good yield
Sand and gravel	Entire area	100	10	12	14	40	20	50	50	30	30	4.2	9.1	20.0
Conemaugh	Plateau	400	8	10	12	40	35	200	165	165	130	10.2	29.0	55.5
Allegheny	Plateau	400	8	10	12	40	60	200	190	140	130	8.7	24.6	64.0
Post-Pottsville	Valley and Ridge	400	6	8	12	40	20	200	200	180	180	5.5	15.8	51.0
Pottsville	Plateau	400	8	10	12	40	30	200	100	170	70	9.4	37.7	33.7
	Valley and Ridge	400	8	10	10	40	30	200	200	170	170	8.4	16.3	29.0
Mauch Chunk	Northern anthracite field	400	6	6	8	40	20	200	200	180	180	3.4	5.4	8.4
	Entire area	400	6	8	10	40	25	200	200	175	175	3.4	7.0	17.0
Pocono	Plateau	400	8	12	12	40	40	200	140	160	100	12.4	35.7	47.0
	Valley and Ridge	400	6	6	8	40	20	200	200	180	180	2.2	5.3	15.1
Susquehanna Group	Plateau	400	6	8	10	40	45	200	200	155	155	2.8	7.7	23.0
	Valley and Ridge	400	6	6	8	40	25	200	200	175	175	2.2	4.4	10.7
Oswayo	Plateau	400	8	10	12	40	40	200	200	160	160	16.4	23.0	33.6
Catskill	Plateau	400	6	8	8	40	50	200	200	150	150	3.1	8.7	32.3
	Valley and Ridge	400	6	6	8	40	40	200	200	160	160	1.9	4.1	10.5
Devonian marine beds	Plateau	400	6	6	8	40	30	200	200	170	170	2.5	6.1	16.5
	Valley and Ridge	400	6	6	8	40	25	200	200	175	175	2.1	3.8	9.2
Hamilton and Onondaga	Valley and Ridge	400	6	8	10	40	20	200	200	180	180	3.5	7.8	17.1
Oriskany	Valley and Ridge	400	10	10	12	40	40	200	200	160	160	19.8	28.4	41.7
Helderberg	Valley and Ridge	300	6	8	12	40	40	100	100	60	60	1.6	5.0	20.0
Keyser and Tonoloway	Valley and Ridge	300	6	8	12	40	20	100	76	80	56	2.1	8.0	26.3
Wills Creek, Bloomsburg, and McKenzie	Valley and Ridge	400	6	6	8	40	20	200	200	180	180	2.5	6.1	14.0
Clinton	Valley and Ridge	400	6	6	8	40	20	200	200	180	180	2.5	5.2	10.4
Juniata and Oswego	Valley and Ridge	400	6	6	6	40	30	200	200	170	170	1.8	2.5	4.5
Reedsville	Valley and Ridge	400	6	6	6	40	20	200	200	180	180	1.8	2.5	3.8
Middle Ordovician limestone	Valley and Ridge	300	6	8	10	40	30	100	100	70	70	1.7	4.7	14.2
Beekmantown	Valley and Ridge	300	6	10	12	40	40	100	54	60	14	2.4	16.0	18.7
Mines and Gatesburg	Valley and Ridge	300	6	8	12	40	60	100	100	40	60	4.0	8.3	17.3

Table 3.--Estimated costs of hypothetical wells and ground water in the geologic units of the upper Susquehanna River basin in Pennsylvania

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 Pennsylvania Power and Light Company rate schedules for municipal use.
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.

Geologic unit (Formation or Group)	Area for which well analyses are valid	Yield category	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)					
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Drilling two wells (one production and one exploratory well)	Develop and pump test production well	Casing, and screening production well	Motor, column, shaft, pump, and strainer	Land, pumphouse, meter, wiring, and piping	Contingencies (10% of sum of columns 1 thru 5)	Engineering and administration (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
Sand and gravel	Entire area	Poor	2,500	1,200	2,210	1,400	4,000	1,130	1,870	14,300	40,000	920	800	120	1,840	0.014	5,100
		Medium	3,200	1,200	3,060	1,900	4,000	1,340	2,200	16,900	22,000	1,080	1,700	140	2,950	.011	3,700
		Good	3,800	2,400	3,740	2,600	4,000	1,650	2,730	20,900	12,000	1,340	2,700	160	4,200	.007	2,500
Conemaugh	Plateau	Poor	5,200	500	200	2,950	4,000	1,280	2,120	16,300	78,000	1,040	2,000	120	3,160	.042	15,000
		Medium	7,600	500	280	4,400	4,000	1,680	2,770	21,200	34,000	1,360	3,400	180	4,940	.021	8,000
		Good	10,000	800	400	5,100	4,000	2,030	3,350	25,700	18,000	1,640	6,000	200	7,840	.015	5,600
Allegheny	Plateau	Poor	5,200	500	200	2,750	4,000	1,260	2,090	16,000	89,000	1,020	1,700	110	2,830	.043	16,000
		Medium	7,600	500	280	4,100	4,000	1,650	2,720	20,800	39,000	1,330	3,000	160	4,490	.024	8,500
		Good	10,000	800	400	5,800	4,000	2,100	3,460	26,600	19,000	1,700	6,800	230	8,730	.016	6,200
Post-Pottsville	Valley and Ridge	Poor	3,200	500	140	2,400	4,000	1,000	1,700	12,900	120,000	830	1,050	100	2,000	.051	19,000
		Medium	5,200	500	200	3,600	4,000	1,400	2,200	17,000	52,000	1,090	2,450	140	3,700	.031	11,000
		Good	10,000	800	400	5,400	4,000	2,100	3,400	26,100	24,000	1,670	5,500	220	7,400	.019	6,900
Pottsville	Plateau	Poor	5,200	500	200	2,850	4,000	1,280	2,100	16,100	85,000	1,020	1,800	110	2,930	.041	15,000
		Medium	7,600	500	280	4,900	4,000	1,730	2,850	21,900	27,000	1,400	4,300	200	5,900	.020	7,300
		Good	10,000	800	400	3,650	4,000	1,880	3,110	23,800	17,000	1,520	3,900	150	5,570	.010	4,000
	Valley and Ridge	Poor	5,200	500	200	2,900	4,000	1,300	2,100	16,200	93,000	1,040	1,600	120	2,800	.044	16,000
		Medium	7,600	500	280	3,650	4,000	1,600	2,600	20,200	58,000	1,290	2,450	150	3,900	.031	11.000
		Good	7,600	500	280	4,400	4,000	1,700	2,800	21,300	34,000	1,360	3,400	180	4,900	.022	8,000
Mauch Chunk	Northern anthracite field	Poor	3,200	500	140	1,900	4,000	970	1,610	12,300	189,000	790	700	80	1,570	.065	24,000
		Medium	3,200	500	140	2,300	4,000	1,010	1,670	12,800	116,000	820	1,000	90	1,910	.049	17,000
		Good	5,200	800	200	2,750	4,000	1,300	2,140	16,400	96,000	1,050	1,600	110	2,760	.043	16,000
	Entire area	Poor	3,200	500	140	1,900	4,000	970	1,610	12,300	189,000	790	700	80	1,570	.065	24,000
		Medium	5,200	500	200	2,550	4,000	1,250	2,050	15,700	112,000	1,000	1,400	100	2,500	.047	18,000
		Good	7,600	500	280	3,600	4,000	1,600	2,640	20,200	56,000	1,290	2,500	150	3,940	.030	11,000
Pocono	Plateau	Poor	5,200	500	200	3,200	4,000	1,310	2,160	16,600	64,000	1,060	2,200	130	3,390	.036	13,000
		Medium	10,000	800	400	4,800	4,000	2,000	3,300	25,300	33,000	1,620	4,100	190	5,910	.021	7,800
		Good	10,000	800	400	4,500	4,000	1,970	3,250	24,900	18,000	1,590	5,200	180	6,970	.013	5,000
	Valley and Ridge	Poor	3,200	500	140	2,030	4,000	1,000	1,600	12,500	350,000	800	400	80	1,300	.099	36,000
		Medium	3,200	500	140	2,300	4,000	1,000	1,700	12,800	130,000	820	1,000	90	1,900	.052	19,000
		Good	5,200	500	200	3,600	4,000	1,400	2,200	17,100	54,000	1,090	2,400	140	3,600	.031	11,000
Susquehanna Group	Plateau	Poor	3,200	500	140	1,700	4,000	950	1,570	12,100	242,000	770	600	70	1,440	.080	29,000
		Medium	5,200	500	200	2,650	4,000	1,150	1,900	14,600	91,000	930	1,500	110	2,540	.044	16,000
		Good	7,600	800	280	4,100	4,000	1,680	2,770	21,200	43,000	1,360	2,900	160	4,220	.023	8,600
	Valley and Ridge	Poor	3,200	500	140	1,500	4,000	930	1,540	11,800	328,000	760	400	60	1,220	.094	34,000
		Medium	3,200	500	140	2,100	4,000	990	1,640	12,600	147,000	810	900	80	1,790	.056	21,000
		Good	5,200	500	200	3,100	4,000	1,300	2,150	16,400	68,000	1,050	2,000	120	3,170	.036	13,000
Oswayo	Plateau	Poor	5,200	500	200	3,550	4,000	1,350	2,220	17,000	49,000	1,090	2,500	140	3,730	.029	11,000
		Medium	7,600	500	280	4,100	4,000	1,650	2,720	20,800	42,000	1,330	2,900	160	4,390	.024	9,000
		Good	10,000	800	400	4,700	4,000	1,990	3,280	25,200	35,000	1,610	3,900	190	5,700	.022	7,900
Catskill	Plateau	Poor	3,200	500	140	1,800	4,000	960	1,590	12,200	203,000	780	600	70	1,450	.069	24,000
		Medium	5,200	500	200	2,750	4,000	1,260	2,090	16,000	89,000	1,020	1,700	110	2,830	.043	16,000
		Good	5,200	500	200	4,600	4,000	1,450	2,390	18,300	27,000	1,170	3,700	180	5,050	.020	7,300
	Valley and Ridge	Poor	3,200	500	140	1,400	4,000	920	1,520	11,700	403,000	750	400	60	1,210	.110	42,000
		Medium	3,200	500	140	2,050	4,000	990	1,630	12,500	158,000	800	800	80	1,680	.058	21,000
		Good	5,200	500	200	3,000	4,000	1,290	2,130	16,300	74,000	1,040	2,000	120	3,160	.040	14,000
Devonian marine beds	Plateau	Poor	2,400	500	140	1,600	4,000	860	1,430	10,900	253,000	700	500	60	1,260	.079	29,000
		Medium	2,400	500	140	2,400	4,000	940	1,560	11,900	74,000	760	1,200	100	2,060	.046	17,000
		Good	3,600	500	200	3,550	4,000	1,180	1,960	15,000	43,000	960	2,500	140	3,600	.028	10,000
	Valley and Ridge	Poor	3,200	500	140	1,500	4,000	930	1,540	11,800	328,000	760	400	60	1,220	.094	34,000
		Medium	3,200	500	140	2,000	4,000	980	1,620	12,500	167,000	800	800	80	1,680	.062	22,000
		Good	3,200	500	200	2,800	4,000	1,070	1,700	13,500	71,000	860	1,700	110	2,670	.039	14,000
Hamilton and Onondaga	Valley and Ridge	Poor	2,400	500	140	2,100	4,000	910	1,510	11,560	180,000	740	650	80	1,470	.061	23,000
		Medium	3,600	500	200	2,810	4,000	1,110	1,830	14,050	88,000	900	1,500	110	2,510	.043	16,000
		Good	5,200	500	280	3,680	4,000	1,370	2,250	17,280	48,000	1,110	2,500	150	3,760	.029	10,000
Oriskany	Valley and Ridge	Poor	7,600	500	280	3,860	4,000	1,620	2,680	20,540	49,000	1,310	2,700	150	4,160	.028	9,900
		Medium	7,600	500	280	4,360	4,000	1,670	2,760	21,170	34,000	1,350	3,350	170	4,870	.022	8,100
		Good	10,000	800	400	4,990	4,000	2,020	3,330	25,540	29,000	1,630	4,600	200	6,430	.019	7,200

Table 3.--Estimated costs of hypothetical wells and ground water in the geologic units of the upper Susquehanna River basin in Pennsylvania--Continued

Geologic unit (Formation or Group)	Area for which well analyses are valid	Yield category	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)					
			1 Drilling two wells (one production and one exploratory well)	2 Develop and pump test production well	3 Casing, and screening production well	4 Motor, column, shaft, pump, and strainer	5 Land, pumphouse, meter, wiring, and piping	6 Contingencies (10% of sum of columns 1 thru 5)	7 Engineering and administration (15% of sum of columns 1 thru 6)	8 Total initial cost (sum of columns 1 thru 7)	9 Total initial cost per mgd of design yield	10 Annual payments to retire total initial cost	11 Annual power cost	12 Annual maintenance costs (4% of column 4 and $1,500 to redevelop screened wells)	13 Total annual cost (sum of columns 10 thru 12)	14 Average annual cost per thousand gallons of design yield	15 Average annual cost per mgd of design yield
Helderberg	Valley and Ridge	Poor	2,600	500	140	1,170	4,000	840	1,390	10,640	21,000	680	300	50	1,030	0.057	21,000
		Medium	5,600	500	200	1,630	4,000	1,190	1,970	15,090	75,000	970	950	70	1,990	.027	10,000
		Good	9,800	800	400	2,900	4,000	1,790	2,950	22,640	26,000	1,450	2,700	120	4,270	.013	5,000
Keyser and Tonoloway	Valley and Ridge	Poor	2,600	500	140	1,260	4,000	850	1,400	10,750	150,000	690	400	50	1,140	.044	16,000
		Medium	5,600	500	200	2,060	4,000	1,240	2,040	15,640	47,000	1,000	1,400	80	2,580	.022	7,800
		Good	9,800	800	400	2,860	4,000	1,790	2,950	22,600	16,000	1,450	3,150	110	4,710	.009	3,400
Wills Creek, Bloomsburg, and McKenzie	Valley and Ridge	Poor	2,400	500	140	1,830	4,000	890	1,460	11,220	260,000	720	500	70	1,290	.081	30,000
		Medium	2,400	500	140	2,580	4,000	960	1,590	12,170	100,000	780	1,150	100	2,030	.045	17,000
		Good	3,600	500	200	3,430	4,000	1,170	1,940	14,840	51,000	950	2,300	140	3,390	.031	12,000
Clinton	Valley and Ridge	Poor	2,400	500	140	1,830	4,000	890	1,460	11,220	260,000	720	500	70	1,290	.081	30,000
		Medium	2,400	500	140	2,420	4,000	950	1,560	11,970	120,000	770	1,000	100	1,870	.051	19,000
		Good	3,600	500	200	3,110	4,000	1,140	1,880	14,430	66,000	920	1,950	120	2,990	.038	14,000
Juniata and Oswego	Valley and Ridge	Poor	3,200	500	140	1,600	4,000	940	1,560	11,940	410,000	760	350	60	1,170	.106	40,000
		Medium	3,200	500	140	1,830	4,000	970	1,600	11,240	260,000	720	500	70	1,290	.081	30,000
		Good	3,200	500	140	2,300	4,000	1,010	1,670	12,820	150,000	820	850	90	1,760	.055	20,000
Reedsville	Valley and Ridge	Poor	2,400	500	140	1,600	4,000	860	1,410	10,810	370,000	690	350	60	1,100	.100	38,000
		Medium	2,400	500	140	1,830	4,000	890	1,460	11,220	260,000	720	500	70	1,290	.081	30,000
		Good	2,400	500	140	2,160	4,000	920	1,520	11,640	160,000	740	700	90	1,530	.059	21,000
Middle Ordovician limestones	Valley and Ridge	Poor	2,600	500	140	1,200	4,000	840	1,390	10,670	180,000	680	350	50	1,080	.051	19.000
		Medium	5,600	500	200	1,680	4,000	1,200	1,980	15,160	80,000	970	900	70	1,940	.029	10,000
		Good	7,400	500	280	2,550	4,000	1,470	2,430	18,630	31,000	1,190	2,300	100	3,590	.016	6,000
Beekmantown	Valley and Ridge	Poor	2,600	500	140	1,330	4,000	860	1,410	10,840	130,000	690	450	50	1,190	.037	14,000
		Medium	7,400	500	280	2,680	4,000	1,490	2,450	18,800	27,000	1,200	2,450	110	3,760	.015	5,400
		Good	9,800	800	400	2,330	4,000	1,730	2,860	22,920	16,000	1,470	2,600	90	4,160	.008	3,000
Mines and Gatesburg	Valley and Ridge	Poor	5,600	500	200	1,580	4,000	1,190	1,960	15,030	94,000	960	750	60	1,770	.031	11,000
		Medium	5,600	500	200	2,100	4,000	1,240	2,050	15,690	45,000	1,000	1,550	80	2,630	.020	7,500
		Good	9,800	500	400	2,760	4,000	1,750	2,880	22,090	29,000	1,410	2,550	110	4,070	.015	5,400

Table 4.--Quality of ground water in the geologic units of the upper Susquehanna River basin in Pennsylvania

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

Geologic unit (Formation or Group)	Area in which well analyses are valid	Chemical characteristic category	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Calcium magnesium hardness as $CaCO_3$	Alkalinity	pH	Color	ABS	Remarks
Sand and gravel	Entire area	Good	50	7	0.07	---	8	3.5	4.0		25	4	1.0	0.0	0.4	50	30	---	---	---	---	Water quality variable both
		Medium	52	10	.10	---	12	5.0	7.0		47	10	4.0	.0	3.0	70	50	---	---	---	---	areally and seasonably if
		Poor	56	15	[a]6.0	---	40	16	15		76	14	20	.1	8.0	140	100	---	---	---	---	influenced by river recharge.
Conemaugh	Plateau	Good	49	----	.11	---	15	----	3.5		14	7	2.0	---	.1	120	50	---	---	---	---	Acid water with high concentra-
		Medium	52	----	.13	---	28	7	5.0		130	16	5.0	.2	.7	180	100	---	---	---	---	tions of iron near mining
		Poor	54	----	.26	---	52	----	25		190	52	10	---	28	280	210	---	---	---	---	operations.
Allegheny	Plateau	Good	50	----	----	---	6	10	3.0		54	8	1.0	---	.0	40	25	---	---	---	---	Acid water with high concentra-
		Medium	51	----	.11	---	36	18	5.0		120	12	1.5	---	.3	150	120	---	---	---	---	tions of iron near mining
		Poor	52	----	----	---	87	42	18		180	210	2.0	---	5.0	440	300	---	---	---	---	operations.
Post-Pottsville	Valley and Ridge	Good	--	----	----	---	---	----	----		---	---	---	---	---	---	---	---	---	---	---	Acid water with high concentra-
		Medium	53	8	.1	---	21	6.8	7.8	1.6	51	7	21	---	22	130	80	---	---	---	---	tions of iron near mining
		Poor	--	----	----	---	---	----	----		---	---	---	---	---	---	---	---	---	---	---	operations.
Pottsville	Plateau	Good	50	6.4	[a]1.0	---	20	6.0	6.0		20	7	1.0	---	.0	85	60	---	---	---	---	Acid water with high concentra-
		Medium	52	7.7	[a]6.0	---	33	16	11		60	35	7.5	---	.1	150	100	---	---	---	---	tions of iron near mining
		Poor	53	8.4	[a]25	---	75	28	53		160	160	30	---	.5	410	210	---	---	---	---	operations.
	Valley and Ridge	Good	--	----	----	---	---	---	----		---	---	.0	---	---	20	14	9	6.7	---	---	A few samples contain excess
		Medium	--	----	.0	---	---	---	----		---	---	1.5	---	---	45	33	27	6.8	---	---	iron, are hard, and contain
		Poor	--	----	----	---	---	---	----		---	---	3.0	---	---	70	52	45	6.9	---	---	hydrogen sulfide.
Mauch Chunk	Plateau	Good	49	----	----	---	---	---	----		---	---	---	---	---	---	---	---	---	---	---	
		Medium	51	----	[a]26	---	72	21	125		138	[a]313	70	---	.1	[a]669	266	---	---	---	---	
		Poor	53	----	----	---	---	---	----		---	---	---	---	---	---	---	---	---	---	---	
	Valley and Ridge	Good	--	----	[a].05	---	---	---	---		---	20	1.5	---	---	65	65	50	6.9	---	---	
		Medium	54	11	.1	---	50	5.7	14		120	40	2.5	.1	2.1	120	90	70	7.2	---	---	A few samples indicate high
		Poor	--	----	.5	---	---	---	---		---	60	3.5	---	---	180	120	80	7.4	---	---	nitrate concentrations.
Pocono	Plateau	Good	48	----	[a].3	---	22	6.0	13		21	5	1.0	---	.2	30	25	---	---	---	---	
		Medium	49	16	[a].6	---	43	8.8	64		48	6	6.5	.1	1.8	100	60	---	---	---	---	
		Poor	51	----	[a]2.0	---	49	9.2	90		190	21	70	---	3.5	320	100	---	---	---	---	Saline water at depth.
	Valley and Ridge	Good	--	----	[a]2.0	---	---	---	----		---	---	---	---	---	---	---	---	---	---	---	
		Medium	57	----	[a]2.7	---	10	---	2.4		40	3	1.0	---	---	39	32	---	---	---	---	
		Poor	--	----	[a]3.4	---	---	---	----		---	---	---	---	---	---	---	---	---	---	---	
Catskill	Plateau	Good	50	10	.02	---	20	4.5	7.0		64	6	3.0	---	.2	100	75	---	---	---	---	
		Medium	50	12	.09	---	26	6.0	11		110	10	4.0	---	1.0	140	100	---	---	---	---	
		Poor	52	13	.20	---	37	8.5	23		130	23	14	---	3.0	160	120	---	---	---	---	Saline water at depth.
	Valley and Ridge	Good	54	----	.0	---	18	---	10		40	10	3	---	6	110	60	62	7.3	0	---	
		Medium	54	12	.15	---	27	13	17		95	17	8	---	18	120	75	70	7.4	3	---	
		Poor	54	----	.21	---	28	---	18		100	25	10	---	[a]45	170	95	80	7.4	17	---	
Devonian marine beds	Plateau	Good	52	6	.1	---	8	4	10		160	3	3.0	---	.0	150	60	---	---	---	---	
		Medium	52	22	.25	---	29	10	50		195	6	72	.0	.1	300	125	---	---	---	---	Saline water at relatively
		Poor	53	23	[a].50	---	66	16	250		200	13	[a]590	---	.4	[a]1,100	240	---	---	---	---	shallow depths.
	Valley and Ridge	Good	54	----	.20	---	7	----	4		60	4	3	---	.0	75	60	---	---	---	---	
		Medium	54	----	.21	0	24	----	12		100	13	10	.0	.5	180	90	250	7.9	15	---	
		Poor	55	----	.22	---	28	----	19		140	32	15	---	8	250	140	---	---	---	---	
Hamilton and Onondaga	Valley and Ridge	Good	53	----	.1	---	30	5	3		90	14	0	---	.1	110	70	50	6.9	0	---	
		Medium	55	----	[a].7	---	50	8	10		130	60	1	---	.1	160	95	80	7.1	5	---	H_2S has been reported from
		Poor	56	----	[a]3.0	---	60	26	17		150	110	7	---	.3	190	140	100	7.5	10	---	a few wells
Oriskany	Valley and Ridge	Good	53	----	.0	---	15	----	2		42	6	.6	---	2	60	45	38	7.0	0	---	
		Medium	53	----	.2	---	18	5.8	3		60	10	1.0	---	3	120	85	90	7.3	0	---	
		Poor	54	----	[a].4	---	52	----	5		100	34	2.7	---	6	180	150	110	7.8	6	---	
Helderberg	Valley and Ridge	Good	51	----	---	---	76	11	3		190	20	4	---	3	200	170	---	---	---	---	2,300 ppm $CaSO_4$ reported
		Medium	53	----	.0	---	95	13	4		200	44	6	---	9.8	280	250	115	7.7	0	---	from one well;
		Poor	58	----	---	---	110	14	20		200	67	8	---	15	400	310	---	---	---	---	$>$1,700 ppm SO_4
Keyser and Tonoloway	Valley and Ridge	Good	51	10	.0	---	57	13	4.7		180	20	1.3	.0	1	190	150	130	7.4	0	---	A few samples indicate
		Medium	53	12	.02	---	61	25	6.0		200	50	3	.05	2	230	180	160	7.6	0	---	high nitrate
		Poor	54	13	.15	---	79	38	13		220	60	8	.1	7	320	210	170	7.9	0	---	concentrations.
Wills Creek, Bloomsburg, and McKenzie	Valley and Ridge	Good	53	----	.07	---	60	18	3		220	20	2	---	3	160	90	90	7.0	0	---	Greater than 700 ppm
		Medium	53	----	.1	---	83	32	5		260	20	3	---	9.2	250	190	130	7.5	0	---	$CaSO_4$ and 500 ppm SO_4
		Poor	53	----	.1	---	89	60	6		280	85	11	---	21	320	300	180	7.8	0	---	reported from 2 wells.
Clinton	Valley and Ridge	Good	51	----	.01	---	2	----	1		12	2.5	.1	---	.06	55	22	50	6.9	0	---	1,700 ppm NaCl reported
		Medium	54	5.9	.20	---	2.4	2.5	3		15	3.5	.6	---	.10	110	48	90	7.1	3	---	from one well;
		Poor	54	----	[a].40	---	11	----	4		35	4.0	1.5	---	.21	140	85	140	7.4	10	---	$>$1,000 ppm Cl.
Juniata and Oswego	Valley and Ridge	Good	--	----	.0	---	---	----	-----		---	----	0	---	-----	35	15	11	6.1	0	---	
		Medium	52	----	.0	---	32	17	2		160	20	0	.1	.0	82	28	24	6.7	0	---	
		Poor	--	----	.0	---	---	----	-----		---	----	2	---	-----	110	50	42	7.3	2	---	
Reedsville	Valley and Ridge	Good	52	----	.09	---	26	----	8		140	10	1	---	0	120	60	80	7.4	---	---	A few samples indicate high
		Medium	54	----	.20	---	28	----	11		150	15	1	---	.05	140	100	95	7.8	---	---	nitrate concentrations and
		Poor	56	----	[a].45	---	30	----	14		160	20	2	---	.10	150	120	100	8.0	---	---	small quantities of H2S
Middle Ordovician limestones	Valley and Ridge	Good	--	----	.0	---	---	----	-----		---	----	.6	---	----	70	60	---	---	---	---	A few samples indicate
		Medium	53	5.5	.005		14	3.8	1.3	.7	55	6.3	1.3	.0	.24	90	78	---	---	---	---	high nitrate
		Poor	--	----	.01	---	----	----	-----		---	----	2.0	---	----	98	95	---	---	---	---	concentrations.
Beekmantown	Valley and Ridge	Good	51	7	,01	---	35	17	3.2	.8	180	11	2	.0	8	190	190	170	7.6	0	---	A few samples indicate
		Medium	52	8	.03	---	49	24	4.7	1.1	220	12	5	.0	14	220	200	180	7.6	5	---	high nitrate
		Poor	53	9	.20	---	60	29	6.8	1.7	280	15	8	.1	18	260	250	190	8.0	10	---	concentrations
Mines and Gatesburg	Valley and Ridge	Good	--	-----	.01	---	---	----	-----		---	----	1.5	---	----	140	110	120	7.4	0	---	A few samples indicate
		Medium	52	----	.08	---	30	----	-----		150	3	3.0	---	2.2	190	130	150	7.7	2	---	high nitrate
		Poor	--	----	.16	---	---	----	-----		---	----	3.7	---	----	330	200	210	8.0	5	---	concentrations

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

Table 5.--Cross reference of geologic units and water service areas in the upper Susquehanna River basin in Pennsylvania

U indicates that the corresponding geologic unit underlies the water-service area.
W indicates that the corresponding geologic unit is within 1 mile of the water-service area.
Physiographic Region: P indicates that the water-service area is in the Appalachian Plateau Province; M indicates that the water-development area is in the Valley and Ridge Province of the Mountainous area.

County	Water-service area	Physiographic Region	Geologic unit																					
			Pleistocene	Pennsylvanian				Mississippian		Devonian						Silurian				Ordovician				Cambrian
				Post-Pottsville						Susquehanna Group														
			Sand and gravel	Undifferentiated	Conemaugh	Allegheny	Pottsville	Mauch Chunk	Pocono	Undifferentiated	Oswayo	Catskill	Marine beds	Hamilton and Onondaga	Oriskany and Helderberg	Keyser, Tonoloway, and Wills Creek	Bloomsburg and McKenzie	Clinton	Tuscarora	Juniata and Oswego	Reedsville	Middle Ordovician limestones	Beekmantown	Mines and Gatesburg
Bradford	Sayre	P	U							U														
	Towanda	P	U							U														
Cambria	Barnsboro	P			U	U																		
	Patton	P			U	U																		
	Spangler	P			U	U																		
Cameron	Emporium	P	U						W		W	U	U											
Centre	Bellefonte	M														W		W	W	W	W	U	U	W
	Philipsburg	P			W	U	W	W	W															
	State College	M																					U	W
Clearfield	Clearfield	P			W	U	U																	
	Curwensville	P			W	U	U	W	W															
	Du Bois	P			U																			
	Houtzdale	P			U	U																		
	Shawville	P			W	W	U																	
Clinton	Lock Haven	M	U										U	U	U	U		W	W					
	Mill Hall	M											W	W	W	U		U	U	W	W			
	Renovo	P	U			W	W	W	W		U	U												
Columbia	Berwick	M	U										W	U		U	W							
	Bloomsburg	M	U										W	U	U	U	U	U						
Lackawanna	Clarks Summit	P								U														
	Scranton	M	U	U			U	W	W	W	W													
Luzerne	Freeland	M		U			U	W																
	Hazelton	M		U			U	U																
	Wilkes-Barre	M	U	U			W	W	W	W		W												
Lycoming	Jersey Shore	M	U										U	U	U		U	W						
	Hughesville	M	U										U	U										
	Muncy	M	U										W	U	U		U	W						
	Williamsport	M	U							U				U	U		U	W	W					
Montour	Danville	M	U										W	U	U	U	U	W	W					
Northumberland	Milton	M	U											W	W	U	U							
Susquehanna	Susquehanna	P	U							U														
Tioga	Elkland	P	U										U											
	Mansfield	P	U									U	U											
	Wellsboro	P	U									W	U											
Union	Lewisburg	M	U											W	U	U	W							
Wyoming	Tunkhannock	P	U							U														

Table 5.--Cross reference of geologic units and water-service areas in the upper Susquehanna River basin in Pennsylvania

U indicates that the corresponding geologic unit underlies the water-service area.
W indicates that the corresponding geologic unit is within 1 mile of the water-service area.
Physiographic Region: P indicates that the water-service area is in the Appalachian Plateau Province; M indicates that the water-service area is in the Valley and Ridge Province of the

County	Water-service area	Physiographic Region	Geologic unit: Pleistocene	Pennsylvanian				Mississippian		Devonian						Silurian				Ordovician				Cambrian
					Post-Pottsville					Susquehanna Group														
			Sand and gravel	Undifferentiated	Conemaugh	Allegheny	Pottsville	Mauch Chunk	Pocono	Undifferentiated	Oswayo	Catskill	Marine beds	Hamilton and Onondaga	Oriskany and Helderberg	Keyser, Tonoloway, and Wills Creek	Bloomsburg and McKenzie	Clinton	Tuscarora	Juniata and Oswego	Reedsville	Middle Ordovician limestones	Beekmantown	Mines and Gatesburg
Bradford	Sayre	P	U							U														
	Towanda	P	U							U														
Cambria	Barnsboro	P			U	U																		
	Patton	P			U	U																		
	Spangler	P			U	U																		
Cameron	Emporium	P	U						W		W	U	U											
Centre	Bellefonte	M															W	W	W	W	W	U	U	W
	Philipsburg	P			W	U	W	W	W															
	State College	M																					U	W
Clearfield	Clearfield	P			W	U	U																	
	Curwensville	P			W	U	U	W	W															
	Dubois	P			U																			
	Houtzdale	P			U	U																		
	Shawville	P			W	W	U																	
Clinton	Lock Haven	M	U										W	U	U		U	W	W					
	Mill Hall	M											W	W	W		U	U	U	W	W			
	Renova	P	U			W	W	W	W		U	U												
Columbia	Berwick	M	U										W	U		U	W							
	Bloomsburg	M	U										W	U	U	U	U	U						
Lackawanna	Clarks Summit	P								U														
	Scranton	M	U	U			U	W	W	W	W													
Luzerne	Freeland	M		U			U	U																
	Hazelton	M		U			U	U																
	Wilkes-Barre	M	U	U			W	W	W	W		W												
Lycoming	Jersey Shore	M	U										U	U	U		U	W						
	Hughesville	M	U										U	U										
	Muncy	M	U										W	U	U		U	W						
	Williamsport	M	U							U				U	U		U	W	W					
Montour	Danville	M	U										W	U	U	U	U	W	W					
Northumberland	Milton	M	U											W	W	U	U							
Susquehanna	Susquehanna	P	U							U														
Tioga	Elkland	P	U										U											
	Mansfield	P	U									U	U											
	Wellsboro	P	U									W	U											
Union	Lewisburg	M	U											W	U	U	W							
Wyoming	Tunkhannock	P	U							U														