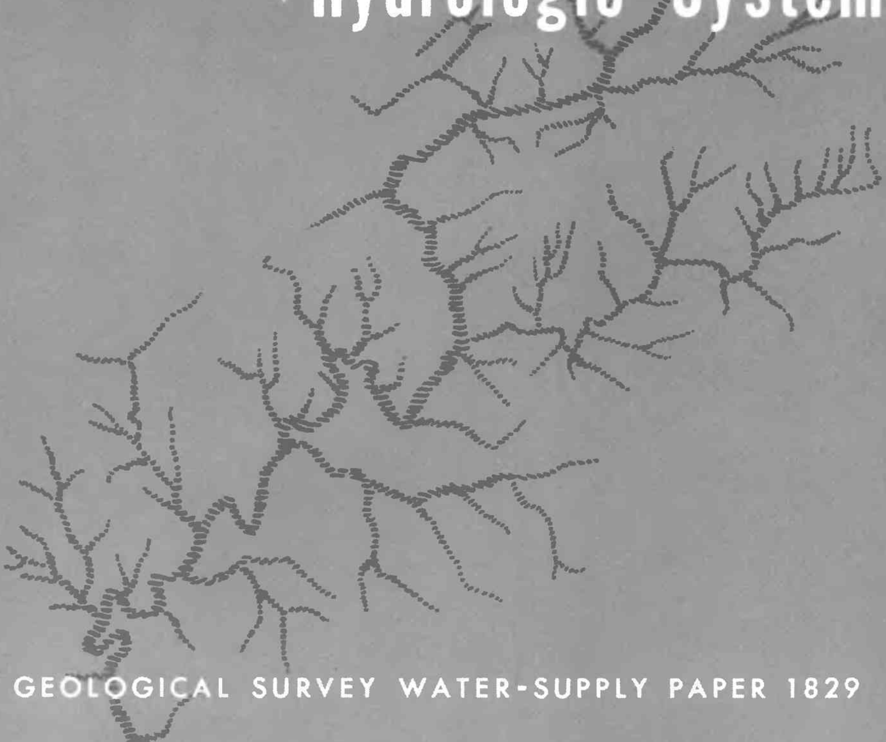
SWATARA CREEK BASIN OF SOUTHEASTERN PENNSYLVANIA

An Evaluation of its Hydrologic System



GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1829

Swatara Creek Basin of Southeastern Pennsylvania

An Evaluation of its Hydrologic System

By WILBUR T. STUART, WILLIAM J. SCHNEIDER, and JAMES W. CROOKS

An evaluation of water resources
in an area of rapidly growing
population and industry

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1829

UNITED STATES DEPARTMENT OF THE INTERIOR

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PREFACE

Accuse not nature! she has done her part: Do thou thine.
—Milton

Each day, it seems, we read about or hear about some "other" area that is being plagued with water pollution or a drought; but except for a twinge of sympathy we usually show no great concern. We appreciate water when we are affected by it personally. Water is important to a thirsty person, to one covered with grime, to a farmer during a drought, or to the owner of a burning building. Today, as members of society, we learn to appreciate the value of water when we are touched individually by the blight of water pollution or water shortage.

We are finding with ever-increasing frequency that water in any one place is part of a system, and that as we use it for our needs in one place, we alter it for use in the same or in another place. We are finding that we must manage this resource intelligently if clean and ample water is to be available for the good of all. Basic to this intelligent management is a comprehensive understanding of the "hydrologic system" that moves water from one place to another. With such an understanding, it may be possible to anticipate and prevent water problems, rather than face the alternative of experiencing and correcting the conditions.

The Swatara basin was chosen for a typical model study area to evaluate the changes that the occupancy of man has imposed on the hydrologic system of the basin. Throughout much of the area, water readily available for man's use is unfit because of natural or man-made pollution. In other parts of the area, demands exceed available supplies.

This report describes the hydrologic system of the Swatara Creek basin as a unit. By showing the relationship of the parts of the basin to the water resources of the whole basin, it can serve as a guide for planning and provide a basis for water management decisions. To make the report more usable, part one is devoted to the evaluation of the water resources and part two to the technical aspects of the hydrology.

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AN EVALUATION OF ITS HYDROLOGIC SYSTEM

By Wilbur T. Stuart, William J. Schneider, and James W. Crooks

Abstract

Local concentrations of population in the Swatara Creek basin of Pennsylvania find it necessary to store, transport, and treat water because local supplies are either deficient or have been contaminated by disposal of wastes in upstream areas. Water in the basin is available for the deficient areas and for dilution of the coal-mine drainage in the northern parts and the sewage wastes in the southern parts.

Swatara Creek drains 576 square miles just east of Harrisburg, Pa., and is the largest tributary to the Susquehanna River from the north side below Harrisburg. It rises in the southern Pocono Mountains and flows southwestward across the Lebanon Plateau. On an average day Swatara Creek discharges more than 630 million gallons into the Susquehanna River at Middletown, Pa. In a year this amounts to about 23 inches of water over the entire basin and is the residual from an average annual precipitation of 45.5 inches. During an average year the flow in Swatara Creek from the upper third of the basin above Harper Tavern is always greater than 1,300 mgd (million gallons per day) for at least 15 days and is always greater than 25 mgd for at least 350 days. The daily streamflow from the basin averages 1.1 mgd per sq mi, but yields from different areas range from 0.97 to 1.22 mgd per sq mi. These variations are caused chiefly by differences in precipitation and land cover. The area of lowest yield is in the valleys west of Tremont, and the highest yields are in the Upper and Lower Little Swatara Creek subbasins.

At high and medium stages the chemical character of the water in the streams is suitable for public and private supplies. At lower stages, depending on the areas and the amounts of contamination by coal-mine drainage and sewage pollution, the natural flow may require some treatment. At low stages the chemical characteristics of the natural flow not affected by man is almost identical with that of the ground water in the area drained by the stream. In general, the total dissolved solids range from about 25 to 400 parts per million and the hardness is as much as about 300 parts per million.

The ground-water increment to the base flow of Swatara Creek averages about 240 mgd, or about 8.8 inches annually, for the basin. Generally, ground-water

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supplies in amounts of less than 0.5 mgd can be developed south of Blue Mountain. Supplies of several million gallons per day have been developed for industrial use from the permeable limestones in the south-central part of the basin. More intensive investigation in other parts of the basin would indicate areas where supplies of more than 0.5 mgd could be developed from properly spaced wells. The chemical character of water from wells depends largely on the host rock. In highly soluble rocks water contains large amount of dissolved solids; in more resistant rocks concentrations are lower. The chemical character of unpolluted ground water generally reflects the composition of the more readily soluble minerals in the local geologic environment. Areas contaminated by septic-tank effluent may have above normal amounts of nitrate and detergent products. Except where polluted, most ground water is suitable for public and industrial uses without extensive treatment.

Sites for storage of surface water exist in the part of the basin lying in the valley and ridge area. As much as 30 to 40 percent of the annual flow could be impounded for release as low-flow augmentation for dilution of mine drainage and other wastes in the basin. Low sediment yields of supplying drainage areas would ensure a long life expectancy of reservoirs at these sites.

Overbank flooding of the main stem of the Swatara Creek and its tributaries has occurred many times in the past. However, it has not been a hazard because urban development has not encroached on the flood plain. An inundation map of the August 1933 flood provides a basis that urban planners may use to avoid future damage. As water in the Swatara Creek moves downstream to the Susquehanna River, the flow is influenced consecutively by a large annual rainfall on the northern valley and ridge area, the wastes of surface and subsurface coal-mining activities, and less annual rainfall on the part of the basin lying in the Lebanon Plateau area; the flow is supplemented and further influenced by many tributaries and by the industrial and domestic wastes that are carried by these secondary streams.

The annual precipitation ranges from 52 inches at the east edge and 49 inches at the west edge of the mountainous part of the basin to about 41 inches at the southwestern part at Middletown. The rainfall generally is adequate during the growing season to mature the crops. The mean annual temperature at Lebanon is about 52°F, and the growing season is about 180 days.

In this report the basin has been divided into eight hydrologic zones, based on runoff, natural use of water, and chemical character of water. Four zones lie in the valley and ridge area, three lie in the Lebanon Plateau area, and one lies in the highland along the southeastern basin boundary. In each of the zones the hydrologic characteristics are virtually the same, but they may be completely different from those in adjacent zones. The boundaries of the zones generally coincide with boundaries between geologic formations, and the areas in each zone include rocks of similar influence on water.

Streams in zone 4 at the northeast edge of the plateau have the highest average surface runoff—from 1.2 to 1.1 mgd per sq mi—whereas those in zone 2 at the northwest edge of the valley and ridge area have the lowest, about 1.0 mgd. Streams in zone 8, along the southeast edge of the basin, have the largest sustained low-flow yield, about 0.26 to 0.19 mgd per sq mi; those in zone 5 overlying the Martinsburg Shale east of Harrisburg have the smallest sustained low-flow yields, 0.03 to 0.01 mgd. Streams in the limestone area of zone 7 have the greatest range in low-flow yields in any one zone—from 0.60 to 0 mgd per sq mi. Low-flow yields in zones 1 through 4 range from 0.13 to 0.03 mgd per sq mi.

Surface flows from zones 1 and 2 are generally acidic and contain high concentrations of sulfate, iron, and total dissolved solids especially where contaminated with mine wastes. Surface flows from zones 3 and 4 are dilute, slightly alkaline, and suitable for public water supplies. Surface flows from zones 5, 6, and 7 are alkaline and contain moderate concentrations of dissolved solids with waters of highest hardness occurring in zone 7. Surface flows from zone 8 are dilute to moderately mineralized and are relatively high in silica concentration. Nitrate concentrations are high in surface flows below sewage outfalls and in ground water contaminated by septic tank effluent and industrial wastes.

Average annual sediment yields of 550 to 650 tons per square mile are characteristic of zones 1 and 2 where strip mining has destroyed the forest cover and coal culm is carried into the streams. From agricultural lands on the Martinsburg Shale in zones 5 and 6, annual sediment yields range from 300 to 350 tons per square mile; but from agricultural lands on the siliceous rocks in zone 8 and zones 3 and 4 in the valley and ridge area, the sediment yield ranges from 200 to 250 tons annually per square mile. Lowest annual sediment yields in the basin are in the forested areas of siliceous rocks in zones 2, 3, 4, and 5, and in the sinkhole topography of the limestones in zone 7 where the yield ranges from 30 to 35 tons and 50 to 60 tons per square mile, respectively.

The amount of ground water that can be developed in the basin is dependent on the ability of the underlying rocks to yield water to wells. More than 300 gpm (gallons per minute) can be obtained from wells in alluvial materials in the valley bottoms and in some of the limestones where large solution channels and fractures are penetrated by the wells. From 50 to 300 gpm can be obtained from wells in loosely cemented sandstones and in fractured limestones. From 10 to 50 gpm can be developed from wells in the shales and harder sandstones. The most dense rocks will yield from 1 to 10 gpm from fractures and crevices. Most wells yield water from the upper 350 feet of the formation, for this part contains the most fractures or solution channels.

Studies show that the velocity at which a contaminant will move downstream in the basin is related to the discharge of the stream at the time. At a stream discharge of about 400 mgd at Pine Grove, a contaminant in Swatara Creek would require about 40 hours to move from Pine Grove to Middletown. As a result of dispersion and dilution, the maximum concentration of the contaminant at Middletown would be less than 20 percent the concentration at Pine Grove under these conditions.

An evaluation of the availability of water in the basin indicates that about 1,239 mgd enters as precipitation, 630 mgd leaves as streamflow, 580 mgd is evaporated and transpired, and 56 mgd is diverted for use by man. Not all the diversions for man's use are lost to the basin, as about 27 mgd is returned as sewage for reuse. About one-fourth of the waste water is returned to the ground and the remainder to stream drainageways. Of that diverted by man, 11.6 mgd is used for public supply and 44.4 mgd for industrial and private supplies. Diversions of streamflow furnish 86 percent of the public supply and

27 percent of the industrial supply, and ground-water sources yield the remainder.

Municipal and private sewage treatment plants are upgrading the waste water in many places, but no provisions are being made for treatment other than natural dilution and assimilation for the 15 mgd of coal-mine drainage in the northern part of the basin. Technology for economic treatment of mine water is not available at this time, although research in this field is being done.

Urbanization eastward from Harrisburg and around Lebanon has increased the population density of the basin. Densities of 500 people per square mile and water use exceeding 2.0 mgd per sq mi can be expected in the future. By the year 2000 the population of the basin may increase 60 percent; and if the per capita rate of use increases 0.5 percent per year the domestic requirements for water will be about two times the present use, or 23 mgd. Similarly, if the present 1:4 ratio of domestic use to industrial use of water continues, at least 89 mgd will be needed for industry in the future. Although an increase to twice the present use of water can be foreseen, or 112 mgd, water for the dilution and assimilation of wastes from treatment systems are not included.

Providing water for dilution of wastes from treatment plants has not been a problem, but in the future the amounts needed for this purpose will be greater as the population increases. As water becomes more valuable, treatment of sewage wastes to reduce the biochemical-oxygen-demand load by at least 80 to 90 percent will be necessary to conserve water for more productive uses. As much as 100 mgd may be needed for waste dilution in the basin by year 2000.

The present trends in suburban and light industrial development will probably persist in the basin. Problems arising through changes in economic value of water, conflicts in use, and alternatives in development are typical of those confronting the manager of a water-resource system.

Evaluation of the Hydrologic System

Introduction

Swatara Creek and its many tributaries are a hydrologic system that when developed as a unit can provide an abundant water supply to meet all present and most future needs in the basin. (See fig. 1). Each year the basin receives, from precipitation, an abundant supply of water that has been a major asset in the cultural, economic, and industrial growth. Although the supply is not optimumly distributed in time or location to provide maximum benefit to man's varied needs, these natural variations have not hampered development. Man, however, in using the water, has imposed stresses on the hydrologic system of the basin. Unwanted results of these stresses often are problems of water supply.

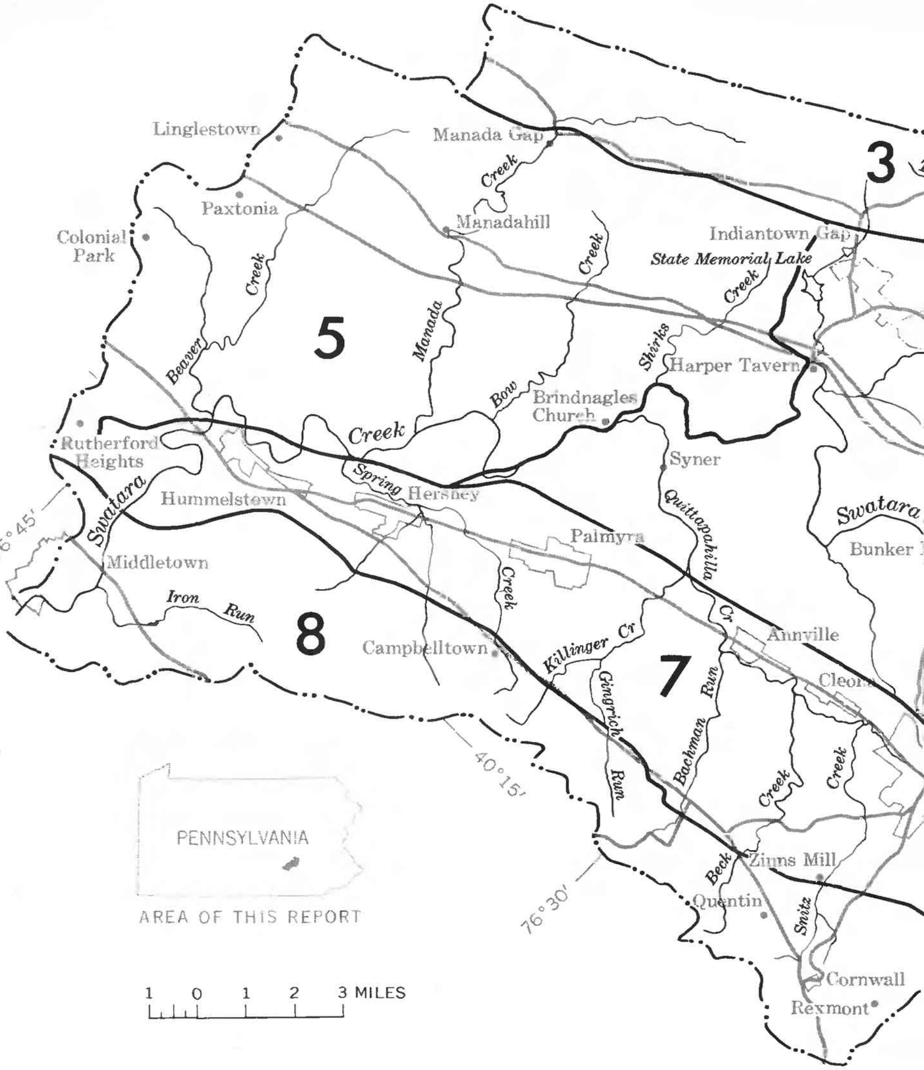
Generally, water shortages or obnoxious reaches of streams are symptoms of growing communities—the inability of water systems or treatment plants to keep pace with demand. The undercapacity of the supply and sewage-treatment systems in the basin are the results of events over three decades. In the depression years of the 1930's money was not available for expansion; in World War II years material and manpower were not available; and in 1950–60 the population explosion and financial inflation made plans obsolete before they could be put into operation.

This part of the report summarizes our present knowledge of the water resources of the Swatara Creek basin—the sources of water, the natural features of the basin controlling the behavior of the water, man's influence, and the problems arising from man's activities. It is based on interpretation of the available data obtained over many years by both governmental and private organizations. It represents primarily a 1-year effort at interpretating these data, although during the investigation some additional information was obtained to support or clarify parts of the existing data.

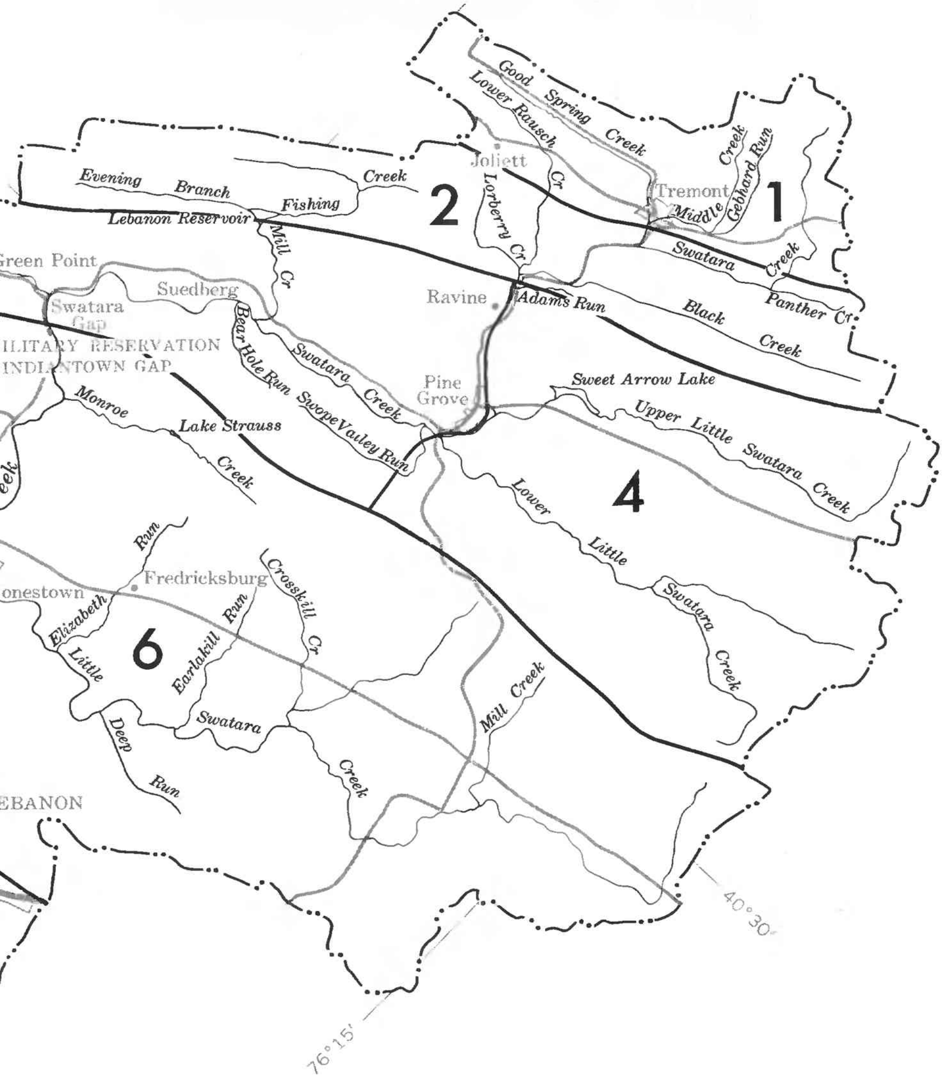
This report aims to show the relationship of distribution and movement of water through the basin in such a manner that when modification of any part of the system is made, the effects will be known in other areas. In other words, as decisions for further developments are made, the effects of such developments can be anticipated and the alternate choices can be considered.

This report, when used as a guide by those managing the water resources, can help alleviate some problems and prevent others. The greatest benefits will accrue if, on the basis of hydrologic knowledge furnished in this report, actions taken to obtain greater utility from the water are not, in themselves, wholly or in part detrimental to the hydrologic system.

FIGURE 1.—Drainage pattern



ologic zones of Swatara Creek basin.



Present Availability of Water

About 1,240 mgd (million gallons per day) of water enter the Swatara Creek system from precipitation. About 49 percent, or 610 mgd, of this is consumed by crops, natural vegetation, evaporation, and man. The remainder, approximately 630 mgd, is available for use by man from streams or from aquifers. The total amount of water available for use is actually much greater than the figure implies. If water quality is not too seriously impaired in the process, water may be reused many times; thus the total amount of water available can be increased to several times the quantity initially available. The initial amount of water available also can be increased by controlled reduction of vegetative growth in the basin. In Swatara Creek basin, water in ground-water storage is considered in balance with the rest of the system so that any consumptive withdrawal of ground water will be reflected in a decrease of surface runoff.

The availability of surface water as streamflow in the Swatara Creek basin is shown on plate 1*C*. The small differences in average annual streamflow are related to differences in land use and precipitation in various parts of the basin. The integrated effect of this areal variability is an average flow of more than 630 mgd of water from the basin into the Susquehanna River. This amount is equivalent to 23.0 inches of water over the entire basin and is the residual from an average annual precipitation of 45.5 inches for the basin. The difference—22.5 inches per year—represents the amount of water transpired by vegetation, evaporated and otherwise used consumptively in the basin.

The average daily flow is subject to seasonal variations, and dependable supplies are governed by the low flows in late summer and fall when streams have receded to their minimum because of evapotranspirative demands. Shown on plate 2*C* are data on the average annual low flows of streams in the Swatara Creek basin. They represent flows to which streams will recede on an average of once in 2 years. Stated another way, in about half of the years, the minimum flows for the year will be lower than those indicated; and in about half of the years, the minimum flows for the year will be greater than those indicated. Data are insufficient to determine the absolute minimum flows, but in general they are about one-third to one-quarter of the average annual low flow. However, many of the smaller streams with drainage areas as large as 5 square miles may cease to flow during such periods.

Ground water is currently used and is available for development throughout the basin. Yields of wells, however, are mostly small to moderate, as shown on plate 1*B* and the success of a well depends directly on the geologic environment. This is particularly true of wells in the area underlain by limestone, where the yield of a well depends almost entirely on the size and number of fractures and solution channels intersected by the well. In the limestone area a well only a few feet away from an unsuccessful dry well may yield an abundant supply.

Present Suitability of Water

Much of the water in Swatara Creek basin is suitable for general use, although for some specific uses treatment may be necessary or desirable. As shown on plate 1*D* most of the water in the basin is suitable for agricultural use, with the exception that acidic mine wastes are corrosive to irrigation systems; also, the acid water is unsuitable for municipal or industrial use unless it has received extensive treatment. Plate 1*E* shows the suitability of water for public supplies, based on U.S. Public Health Service standards. Streams not suitable at present without extensive treatment are the Quittapahilla Creek below Lebanon, Snitz Creek, some reaches of Swatara Creek, and tributaries in the northern part of the basin affected by mine drainage. Ground water near Lebanon is not suitable for domestic use because it contains concentrations of nitrate as high as 150 ppm (parts per million). In the Beaver Creek basin, particularly the Linglestown area, the ground water is being polluted by septic tank effluent, and may not be suitable for public supplies.

On the basis of chemical characteristics such as hardness, dissolved solids, acidity, turbidity, and corrosion or scale-forming tendencies, water in the basin is classified for general industrial use as shown on plate 1*F*. This classification, however, is broad and is offered primarily as an aid in selecting a water supply in one area that is preferable to a source in another area in the basin in terms of the chemical characteristics of the water and its intended use.

Lack of adequate criteria prevents classifying water in Swatara Creek basin for recreation use. However, acidic streams in the headwaters of the basin and much of Quittapahilla Creek below Lebanon are devoid of fish life and are of such poor quality as to be unsuitable for recreational use. In other areas the suitability of the water is such that fish are stocked in several streams, picnic sites have been developed in several areas, and boating is becoming popular in the deeper reaches of Swatara Creek between Hummelstown and Middletown.

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Water Management

In administrating and controlling the water resources of the Swatara Creek basin, the public officials concerned with management of water have three tasks: (1) to plan and develop adequate water supplies, (2) to protect existing supplies in the streams and in the ground from pollution, and (3) to prevent catastrophic incidents either on or by water. However, in carrying out these tasks, management must deal with factors that are of local concern, of basinwide concern, or both. Among the factors which are both local and basinwide are population growth, urbanization, and pollution control. Local factors include water shortages, flood inudation, erosion and sediment movement, development of storage, and competition for available water.

Several areas in the basin now have or will face water problems. Mine drainage from the coal mining regions in the northern part of the basin has caused acidic streamflow on occasions as far downstream as Hummelstown. Suburban growth without sewerage is causing local ground-water pollution in the Beaver Creek basin. Increased future demands for water are likely to accompany further suburban expansion of Harrisburg and Lebanon, and industrial expansion.

According to planning reports on Lebanon and Dauphin Counties, suburban and light-industrial growth is occurring in the basin in the belt between U.S. Route 22 and Blue Mountain. The present band of development through the Hershey, Annville, Palmyra, and Lebanon area is becoming wider and may merge with that along Route 22. The expansion is moving eastward from Harrisburg along the transportation routes; and while residential developments are prevalent, light-industrial and commercial zones are locating at main traffic intersections. Most of the commercial growth is services, food processing, chemicals, and manufactured metal products.

Suburban growth has doubled the population of Dauphin County in the Swatara Creek basin between 1934 and 1960, and estimates indicate a population of 63,000 in the year 2000 for an area of 126 square miles (U.S. Senate, Select Committee on National Water Resources, 1960). For Lebanon County a somewhat lesser density, about 80,000 inhabitants in 265 square miles, is predicted. In changing the land use from a strictly rural to an intensely urban area, the domestic water needs increase a thousandfold—from about 0.002 to 2.0 mgd per sq mi. Future users will need greater amounts, individually and collectively, and new residents will add their requirements to those of the present residents. As more water is used and returned to the streams and the ground, the potential for pollution, both in incidents and magnitude, will also be enlarged.

Present rate of per capita use of water in the basin ranges from 40 gpd (gallons per day) in rural areas to 128 gpd in the cities. In the next few decades the per capita use in the rural areas will increase to about that in the cities. However, the rate of use in the suburban areas is not expected to exceed the present use for cities nor is the domestic use per capita in the cities expected to increase more than 1 or 2 percent per year. Nevertheless, total volume of water for domestic use in the basin will almost double in the next 40 years if the population increases by 60 percent and the water use per capita increases only by 20 percent. Urbanization has already spread into the Beaver Creek basin and will soon spread into the Manada Creek basin and later into the main stem Swatara Creek basin.

This report indicates an ample supply of water is available in the basin. Ground water can be obtained from wells in quantities up to 0.5 mgd per sq mi in most areas, but larger amounts can be developed in the permeable alluvium along the streams. The yields of individual wells range from a few to more than 300 gpm, depending on the water-bearing formations and local geologic conditions. On the other hand, streamflow averages about 1 mgd per sq mi annually over most of the basin, although the sustained or base flows are only a few percent of the average. The areas of lowest sustained flow are in the west-central part of the basin, where there is the greatest urban expansion and consequently the greatest need for water.

Past experience shows that even moderate-sized subdivision developments will find it difficult to develop only local supplies and meet their needs. The Lebanon supply is obtained from Fishing Creek as well as two additional small reservoirs outside the basin. Colonial Park and Paxtonia obtain their supply from the Harrisburg Suburban Water Co. Development of small local surface supplies in zone 5 is not practical. Beaver Creek is not suitable because of the hazard of potential pollution. The flow of Manada Creek is currently developed by the Hershey Water Co. Bow Creek lacks both sustained low flow and adequate reservoir sites. Storage sites on the larger streams in zones 4 and 6 could increase available supplies for use in newly developed areas.

Reservoirs in zones 4 and 6 would occupy a geologic environment in which water can be stored. The fractured and soluable limestones of zones 7 and 8 do not provide such an environment. Reservoirs in zones 1, 2, and 3 would provide a deep storage with small surface area and would have lower evaporation losses, but the quality might be impaired because of acidic mine-water inflow. In zones 4 and 6 storage on small tributaries may have large surface areas, and the loss through evaporation may be excessive, at times exceeding the inflow. In the stored water of zones 1, 2, and 3 chemical and physical changes—precipitation of iron and manganese and entrapment of sediment—may depreciate the quality of water.

Protection of existing supplies in the streams and in the ground are problems inherent in and related to the development of the area. Local disposal of sewage through septic tanks in the Beaver Creek and the Lebanon-Annville areas have polluted the ground water, which in turn alters the chemical character of the streamflow. The western tributary of Beaver Creek, draining from the Colonial Park-Paxtonia area, already shows the influence of urbanization over approximately 20 percent of its area. Streamflow in this tributary in August 1962 was about 226,000 gpd (gallons per day) more than would be expected from natural drainage of ground water in the underlying Martinsburg Shale. Furthermore, the above probable normal concentration of nitrate and chloride as well as the presence of ABS (alkyl-benzyl-sulphonate, a constituent of detergents) indicate that this increase in flow is probably sewage effluent from the development areas.

Wastes added to ground water are slow to spread and difficult to eliminate even after long periods of time. In some places such pollution may continue to exist in ground water and in the base flow of streams many years after the source has been removed. In general, septic fields can be used for the disposal of small volumes of wastes if the soils are sufficiently permeable and the disposal areas are widely separated to provide dilution. In areas underlain by the Martinsburg Shale and rocks of similar low permeability, large volumes of wastes require collection and treatment before disposal into a water course. Although modern community sewage-treatment facilities are more desirable than septic-tank systems, streamflow during periods of low flow may be insufficient to dilute the effluent properly. Thus for certain periods, the streamflow below these treatment plants will be unsuitable for many uses in spite of normally adequate treatment.

Both organic and inorganic wastes contribute to pollution in the Swatara Creek basin. Organic wastes include mainly domestic sewage and waste from food-processing plants, such as dairies and meat-packing establishments; and the inorganic wastes are chiefly acid mine water and sediment. Organic wastes can be treated by oxidation in standard treatment plants to remove their contaminating effects. Inorganic wastes cannot be treated by the same process as organic wastes, but must have specific chemical treatment and the products physically separated.

The tasks of management of water resources are similar in the Beaver Creek, Manada Creek, and lower Swatara Creek basins and in the Lebanon, Annville, Palmyra, Hershey, and Hummelstown areas. All are concerned with increased needs for water beyond the supplies available in their immediate areas. All have waste-disposal conditions requiring consideration by the water manager.

Additional small supplies of ground water and larger supplies of surface water can be developed in Swatara Creek basin. Large supplies can be obtained from Swatara Creek; and although the water is at times slightly acid because of mine drainage, it is generally of acceptable quality and requires little treatment other than chlorination and, on occasion, neutralization. Little Swatara Creek has water of good quality and adequate sites for storage reservoirs. However, diversion of water from Little Swatara Creek will reduce the amount of water available for dilution of acidic water in Swatara Creek and would probably result in a lower pH level in Swatara Creek from Jonestown to the point where water from Quittapahilla Creek provides dilution. Although some wells yield large quantities, ground-water development is not practical in the limestone areas around Lebanon because the water is hard and requires extensive treatment before general use. Also, because of the continuity of fissures and solution caverns in the limestone, contamination of wells from distant sources is possible. The development of supplies, chiefly ground water, from the calcite quarries east of Lebanon would have the same disadvantages as wells in limestone.

Large quantities of water will probably not be needed for industrial growth. The quarrying of limestone in the areas north of Palmyra, Annville, and Lebanon may increase slightly but will probably remain fairly stable. Unlike most industries, however, quarrying is not a user but rather a producer of water in that most quarries in this area must be dewatered when operating. Most of this water is pumped into Quittapahilla Creek and its tributaries and ultimately into Swatara Creek. This quarry water is hard and, being alkaline, tends to neutralize the slightly acidic condition in Swatara Creek. It also increases the dissolved solids in Swatara Creek so much that considerable treatment is desirable for most uses.

Although coal mining in the northern part of the Swatara Creek basin will continue to decrease, its effect on the water resources will remain fairly constant for some time, if no new and effective methods are found for treating acid mine waters. In 1961 acid mine drainage averaging about 14.6 mgd was discharged into the headwater tributaries of Swatara Creek from underground operating mines and from overflow of abandoned mines. Good Spring Creek, Lorberry Creek, and Lower Rausch Creek were affected mainly, and this acidity at times was observed far downstream in the Swatara Creek.

Effective management or alleviation of the acid mine water in the northern part of the basin requires continuous surveillance. The drainage of water from the mines did not diminish when mining ceased nor can any great reduction be foreseen in the future. The quality has improved slightly since some of the mines were closed, but there is no basis to expect that improvement will continue without considerable effort to alleviate the causes.

The alleviation of the acid pollution may follow one or a combination of the following accepted practices. One such practice is to isolate abandoned mines. Where abandoned mines are amenable to it, the isolation of the mine from both inflow of water and the discharge of mineralized water offers a means of containment of the problem. The water in the mine may build up strong mineralization and acidity as a result of containment; but since it is stored in one area, the mine water does not contribute to a regional problem. Recent studies by the Geological Survey show that, contrary to past belief, sealing the mine against air circulation does not effectively reduce the acidity and mineralization of mine waters.

Acid mine drainage may be neutralized by addition of limestone, lime in various forms, soda ash, or caustic soda. Stream reclamation by neutralization alone is not always feasible because of the large amount of neutralizing materials needed and the necessity for continuous treatment. Neutralization generally leaves large amounts of dissolved solids in the treated water, making it unsatisfactory for many uses.

Acid mine drainage also may be diverted. This, however, protects one area at the sacrifice of another. Diversion does not reduce the total mineral load carried into the lower watershed, but it may permit disposal in an area where more diluting water is available. Consequently, the mixture may be more acceptable.

Pumping active mines at a uniform rate is also effective. Current practice of pumping water from active mines at a high rate during a few hours takes advantage of off-peak power rates. This practice may build up a dangerous acid concentration beyond the ability of the receiving stream to absorb it. If the same amounts of acid were discharged uniformly over a 24-hour period, the injurious effect on the stream would be greatly lessened.

Storage and flow augmentations also can be used to alleviate the problem. Flow augmentation is accomplished by storage of strongly acid water which is released during periods of higher streamflow or storage of less acid water which is released during periods of low flow for added dilution of mine drainage.

Reduction of contact time of water with the acid-forming materials is also helpful. This method is particularly applicable to strip mining operations and is accomplished either by restoring the natural drainage from open-pit areas to prevent ponding of water after precipitation or by backfilling the pits to eliminate water from the proximity of the formations which contain the acid-forming minerals.

Reducing the inflow to mining areas is another accepted method. This decreases the outflow of mineralized water from the area and can be accomplished either by diverting the surface flow around the area or by transporting the streams across the area in conduits or flumes. Restoration of surface drainage where subsidence has destroyed the original gradient also reduces the inflow into the mines.

In streams affected by acid drainage, the impoundment of the better quality water from the spring period of high runoff could provide dilution water for mixing with the stronger mineralized flows occurring during the summer. Additional water of excellent quality for dilution and low-flow augmentation could be stored on Black Creek and other headwater streams unaffected, or only slightly affected, by mine drainage. In general, storage sites in the basin have capacities of about 30 percent of the total annual flow at the site. Sedimentation throughout much of the basin is not a serious problem, and the useful life of reservoirs may be measured in terms of centuries rather than decades.

At present, potential flooding damage is minimal compared to many areas in Pennsylvania and the Eastern United States Except for some low-lying residential sections at Pine Grove and at Middletown, flood damage is limited to scattered residences on the flood plain. The urban developments in the basin—Pine Grove, Annville, Lebanon, Palmyra, Hershey, and Hummelstown—encroach surprisingly little on the natural flood plains in the Swatara Creek basin in contrast to other parts of the country, where urbanization is concentrated heavily in the valleys with consequent serious periodic damage from floods.

The sparse occupancy of the flood plains in the basin offers an unusual opportunity to prevent increased future flood damages by adopting regulations and zoning to prevent further encroachment.

Understanding the many factors of the hydrologic system in the Swatara Creek basin is needed for intelligent decisions in the future management of water for optimum benefits. Quantity and quality of water are certainly paramount; variability both in time and space must be known. Other factors, too, are important. The relations between streamflow and ground water are important, as are data on traveltime of water in stream channels.

Much of the data needed for intelligent decisions are available; some gaps and shortcomings still exist. Much of the available data are analyzed in the following section to give an understanding of the current hydrologic system of the Swatara Creek basin. Also included are some data on socioeconomic factors which exert dynamic influences on the hydrologic system. For convenience, the data are summarized in table 1 according to zones of hydrologic similarity as shown on plate 1*C*.

TABLE 1.—*Characteristics of hydrologic zones of Swatara Creek basin*

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Environment:								
Physiography	Valley and ridge.	Valley and ridge.	Valley and ridge.	Valley and ridge.	Upland plain.	Upland plain.	Plain	Highland.
Predominating type of bedrock	Sandstone and shale.	Sandstone and shale.	Sandstone and shale.	Sandstone and shale.	Shale	Sandy shale	Limestone	Triassic shale and conglomerate.
Type of land use	Forest and mining.	Forest and mining.	Forest, woodland, agriculture.	Agriculture and woodland.	Agriculture and urban.	Agriculture	Agriculture and urban.	Forest and agriculture.
Areas sq mi	22.9	35.6	68.6	65.1	89.4	188.2	67.3	38.9.
Average annual precipitation inches	46.9	45.9	47.0	47.9	44.5	45.6	43.9	43.0.
Streamflow:								
Average annual surface runoff mgd per sq mi	1.10–1.03	1.03–0.97	1.10–1.03	1.22–1.13	1.16–1.10	1.16–1.10	1.16–1.03	1.10–1.03.
Average annual ground-water flow to stream do	0.50–0.44	0.49–0.37	0.47–0.41	0.44–0.32	0.38–0.32	0.39–0.35	0.60–.041	0.60–.054.
Average annual consumptive use by vegetation do	1.17	1.18	1.18	1.10	0.99	1.04	1.00	0.99.
Average low flow in streams do	0.45–0.06	0.45–0.06	0.13–0.09	0.09–0.03	0.03–0.01	0.05–0.03	0.60–0	0.26–0.19.
Sediment yield tons per sq mi	650–550	650–30	250–30	250–30	350–30	350–30	60–50	250–200.
Ground water:								
Yield of wells gpm	50–300	1–300	1–50	1–50	1–50	1–50	1->300	1->300.
Chemical characteristics of water:								
pH	6.5–3.0	6.5–3.0	7.0–6.0	7.0–6.0	7.5–6.5	7.5–6.5	8.5–7.0	8.0–6.0.
Solutes ppm	1,000–50	1,000–15	50–15	75–20	300–25	300–25	700–100	600–20.
Hardness do	700–50	700–10	30–10	40–10	220–15	220–15	600–75	400–10.
Acidity do	100–0	100–0	0	0	0	0	0	0.
Alkalinity do	100–0	100–0	20–5	40–10	150–30	150–30	250–150	200–50.
Sulfate do	800–50	800–3	10–3	10–3	30–10	30–10	80–20	350–3.
Iron and manganese do	40–1	40–0	1–0	1–0	1–0	1–0	1–0	1–0.
Nitrate do	1–0	1–0	5–1	10–1	10–1	10–1	150–1	150–1.

Technical Aspects of the Hydrology

Topography

Swatara Creek, one of the larger tributaries to the lower part of the Susquehanna River, drains 576 squares miles just east of Harrisburg, Pa. The drainage area lies along the southeast edge of the Valley and Ridge province.

Topographic relief is flat to gently rolling in the central part of the basin—the Lebanon Plateau area—and may locally be about 100 feet. In the northern part of the basin—the valley and ridge area—relief is more pronounced but not rugged and locally is as much as 800 feet. The southern part is a highland area of moderate relief. The topography is shown in figure 2.

Swatara Creek heads in the southern Pocono Mountains, near Tremont, in Schuylkill County at an altitude of about 1,700 feet. It flows southwestward, descending about 30 feet per mile from Tremont through a gap in Second Mountain where it is joined by Upper Little Swatara Creek at Pine Grove. Swatara Creek then flows southward on a flatter gradient of about 10 feet per mile through Swatara Gap in Blue Mountain at an altitude of 400 feet. At Swatara Gap the creek drains 169 square miles, about one-third of the area of the entire basin. Below Swatara Gap, the creek meanders southwestward at a gradient of about 3 feet per mile across the plain of the Lebanon Plateau where its flow is increased by many tributaries. Swatara Creek enters the Susquehanna River at an altitude of about 300 feet at Middletown, 5 miles downstream from Harrisburg.

Population Characteristics

The Swatara Creek basin in 1960 had a population of about 126,200 people. Of every 100 persons, 56 lived in cities or unincorporated suburban communities; the remainder lived in rural areas in the upper reaches of the small watersheds along the south and north boundaries of the area.

The 1960 census data indicate that the population density in the basin averaged 219 people per square mile, or about 0.9 of the State

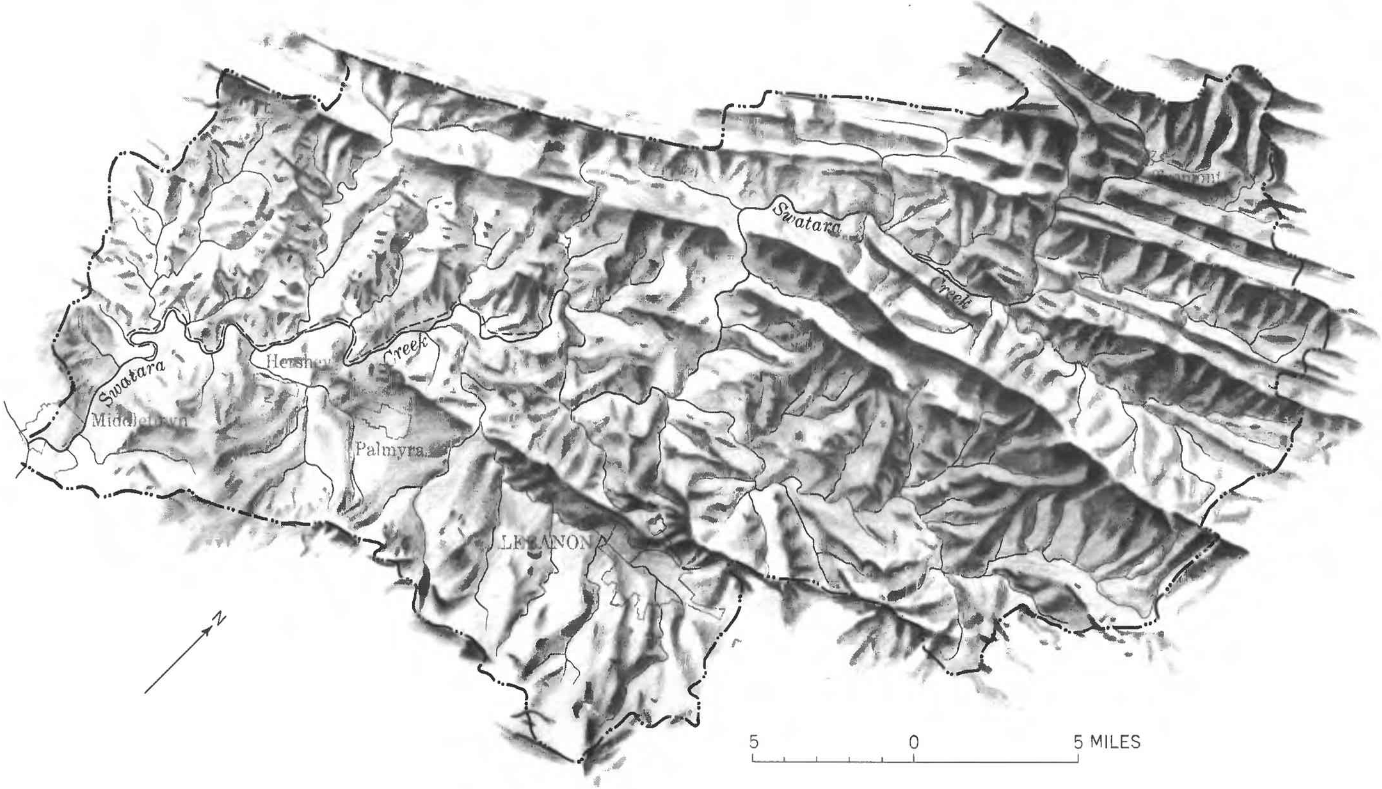

FIGURE 2.—Topography of Swatara Creek basin.

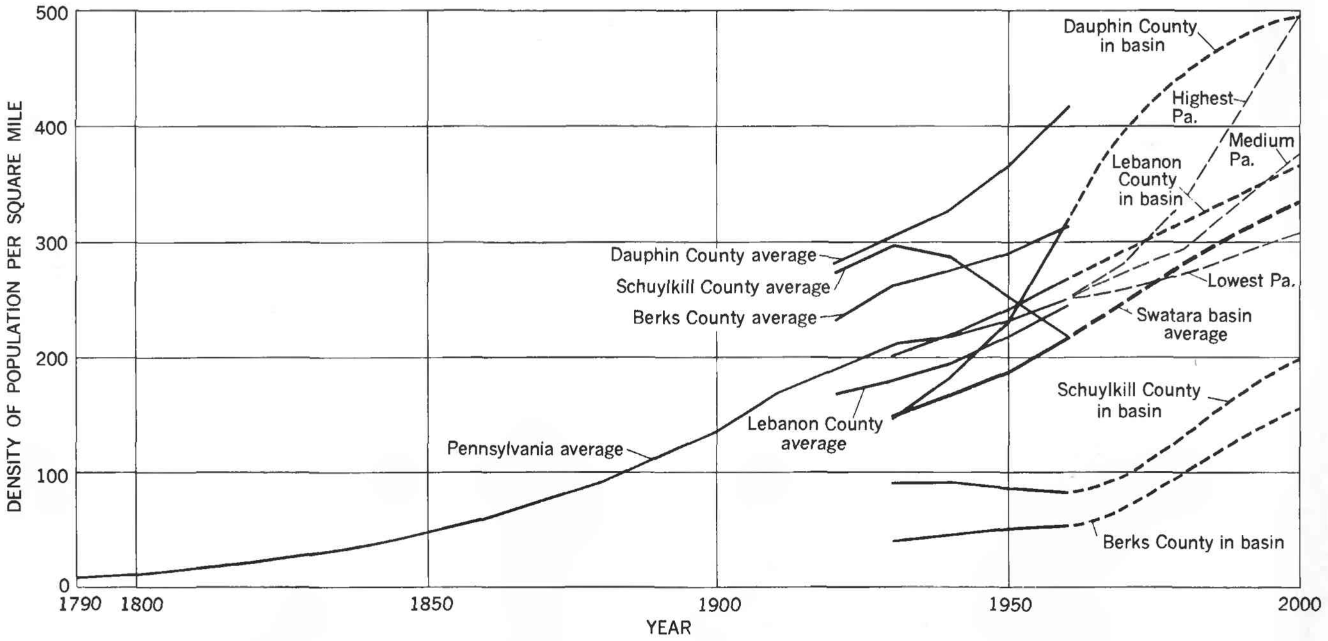

FIGURE 3.—Population density and growth rate. From U.S. Senate Select Committee on National Water Resources (1960).

average of 252. The greatest concentration—323 per square mile—is adjacent to Harrisburg in Dauphin County; Lebanon County has 270, Schuylkill County has 85, and Berks County has 54 per square mile as shown in figure 3. In the basin, Dauphin and Lebanon Counties have population densities greater than the State average, and the growth in Dauphin County has doubled from 1934 to 1960. This increase in Dauphin County has been more rapid than the average for the State owing to the expansion of suburban Harrisburg into the basin. The population of Lebanon County also has increased, but not as rapidly as that of Dauphin County. Schuylkill and Berks Counties are rural, and the population of the parts of these counties in the basin has changed only slightly.

Land Use

Land use modifies the hydrology of the basin more than any other factor. Change in cover from forest to agriculture changes the amount of water consumed on the land and either increases or decreases the runoff reaching the streams. Changes from crop cover to urban or industrial development increases the runoff and makes possible increased erosion of the soil cover. Concentration of man's activities requires diversions of flow to satisfy his needs and often requires additional flow for disposal of his waste products.

The Swatara Creek basin, with 1.28 percent of Pennsylvania's land area and 1.12 percent of the State's population, is composed of parts of four counties. It occupies 6.3 percent of Berks County, 23.1 percent of Dauphin County, 71.4 percent of Lebanon County, and 16.4 percent of Schuylkill County. Most of the land, as shown in table 2, is in agriculture and woodland. The urbanized areas are in the Cumberland Plateau east of Harrisburg and surrounding Lebanon, and mining is limited to the northern parts of the basin.

The major change in land use in the basin is the conversion of farmland to other uses. Since 1954 about 7,100 acres has been diverted

TABLE 2.—*Division of basin by county and land use*

County	Part of basin in county		Percent of basin by land use			
	Sq mi	Percent	Farmland	Woodland	Urban or built-up	Strip mines or quarries
Berks	55.0	10.3	67.0	32.0	1.0	
Dauphin	126.0	21.5	67.9	24.8	7.3	
Lebanon	265.0	45.0	67.0	29.3	3.3	0.6
Schuylkill	130.0	23.2	35.6	58.9	0.6	4.9

from agricultural production each year for urban development and highway expansion. In 1961 the basin contained about 1,850 farms averaging slightly less than 100 acres each. This size is about 20 percent below the statewide average.

Cropland in production is the largest user of water in the basin. Without irrigation, cropland uses about 27 inches of precipitation annually, or 1.3 mgd per sq mi.

Irrigation of farm crops in the basin is not practiced on a continuing basis for economic reasons. The need for irrigation on the typical forage and grain type feed crops has not been justified because rainfall has generally been adequate in amount and time-distribution to mature those crops with an adequate yield. According to the county agent for Schuylkill County, supplemental irrigation might be used in about 1 year out of 8 years. However, should the crop use change from stock feed to truck farm or vegetable crops, irrigation may be economical.

Mineral Resources

The removal and processing of mineral resources caused changes in the hydrology of the basin. Streamflow is affected by diversions, importation, and consumptive use of water for processing of mineral products. Ground-water flow is altered by artificial drainage in mines and quarries. The character of the water is altered by introduction of silt and soluble materials.

Water from anthracite coal mines and preparation plants added to Swatara Creek or its tributaries is acidic, culm laden, and highly mineralized. Water from iron ore mines and limestone quarries is not acidic but is generally more concentrated in dissolved and suspended solids than the natural streamflow of the area.

Anthracite coal is mined by underground and open-pit methods in the northeastern part of the basin, but at a considerably lower rate than in the past. In the basin underground-mining operations generally have been replaced by open-pit extraction through the development of large earth-moving machinery. The annual production rate of coal has not decreased as rapidly in the basin as for the whole State because of the ease of obtaining coal in large quantities by open-pit methods. Production in the basin in 1930 was estimated to be about 2 million tons and in 1961 about five to six hundred thousand tons.

Iron ore and its associated minerals are mined in the southeastern part of the basin near Cornwall. Limestone for chemical and agricultural purposes is mined or quarried in the belt of formations extending across the basin from Hummlestown eastward beyond Lebanon. Limestone quarrying is a growing industry, and the rate of production has been increasing since 1940.

The minerals produced in the four-county area in 1959 and their order of value are shown in table 3. Production of stone, sand and gravel, and clay are common in all counties; but, where found, iron ore, coal, and lime have a large dollar value. New product uses will undoubtedly cause increased demand for clay, shale, and limestone.

TABLE 3.—*Minerals produced, in order of rank*

Rank	Berks County	Dauphin County	Lebanon County	Schuylkill County
1	Cement	Stone	Iron ore	Coal.
2	Iron ore	Coal	Lime	Stone.
3	Stone	Clay	Stone	Sand and gravel.
4	Clay	Sand and gravel	Copper	Clay.
5	Sand and gravel	Lime	Cobalt	

Precipitation

Average annual precipitation for the Swatara Creek basin ranges from 40 inches near the mouth of Swatara Creek, at Middletown, to 52 inches over Blue Mountain on the east edge of the basin. Figure 4 shows this areal distribution. The two areas of high annual precipitation in the valley and ridge part are the result of orographic effects related to increased altitudes. Except for the small area of lower precipitation near Middletown, the Lebanon Plateau has a fairly uniform annual precipitation of about 44 inches.

The precipitation over the Swatara Creek basin is well distributed throughout the year; it follows a cyclical pattern in which the highest average is in July and the lowest is in February. At Lebanon, these averages are 4.53 inches for July and 2.52 inches for February. Because of below-freezing temperatures, much of the precipitation during the winter is snow. The maximum 24-hour precipitation for the basin, recorded at Lebanon on July 22, 1945, was 5.95 inches. However, only 5 miles northeast of the basin, at Pottsville, 9.00 inches of precipitation was recorded for a 24-hour period on July 8, 1935. Heavy rains such as these are usually associated with thunderstorms and are therefore local rather than basinwide.

There are no observable long-term trends in precipitation for the Swatara Creek basin. The records of annual precipitation for Lebanon, Pa. (fig. 5), as well as those of other locations in and near the basin show no repetitive pattern of yearly fluctuations.

Evaporation as recorded by the U.S. Weather Bureau for the class A type evaporation pan is 45 inches annually for the basin at alti-

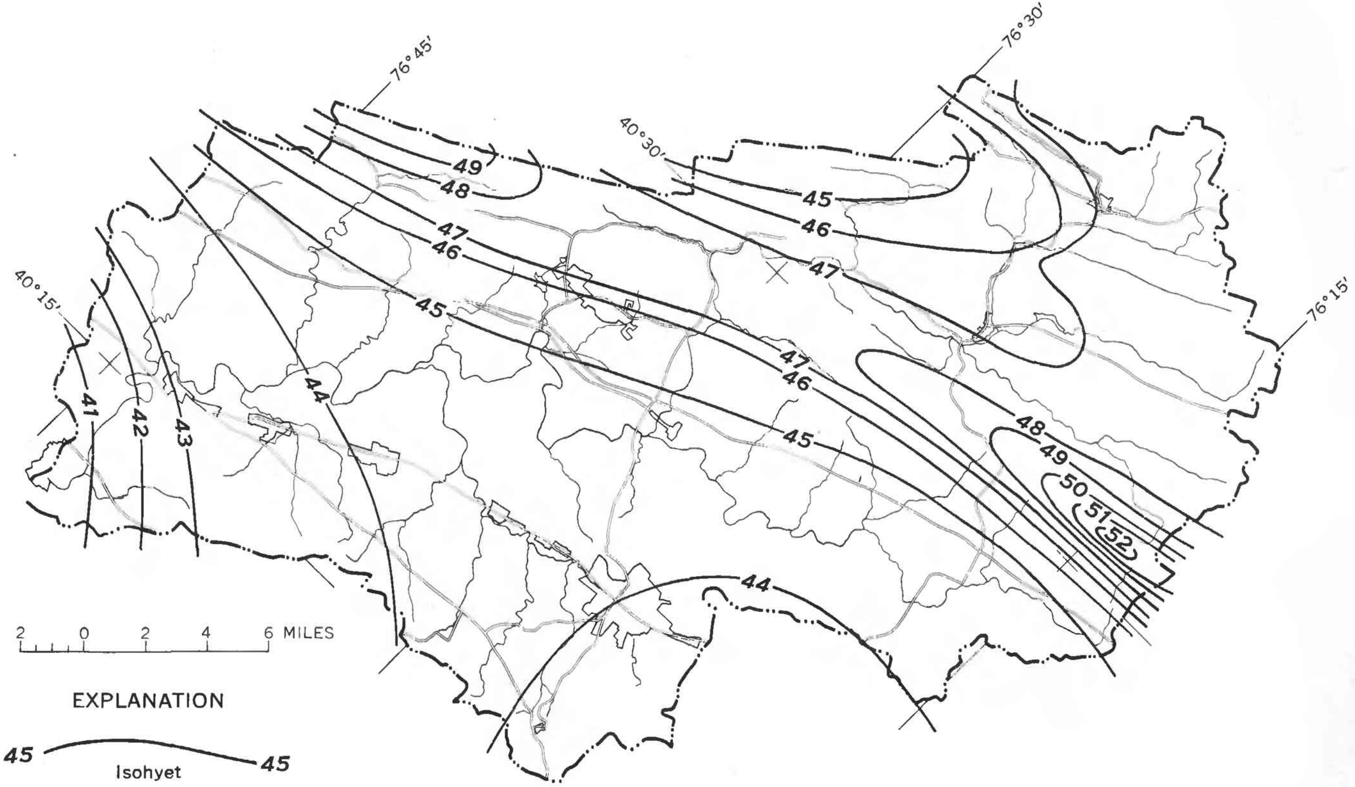

FIGURE 4.—Average annual precipitation. Adapted from "Precipitation Map of Susquehanna River Basin," by T. J. Nordenson, U.S. Weather Bureau.

tude 500 feet. For each 300 feet increase in altitude, the rate decreases about 1 inch.

Evaporation from lake surfaces is about 34 inches annually at altitude 400 feet and decreases approximately 1 inch for each 200 feet increase in altitude. Evaporation during the growing season from May through October averages 73 percent of the annual amount.

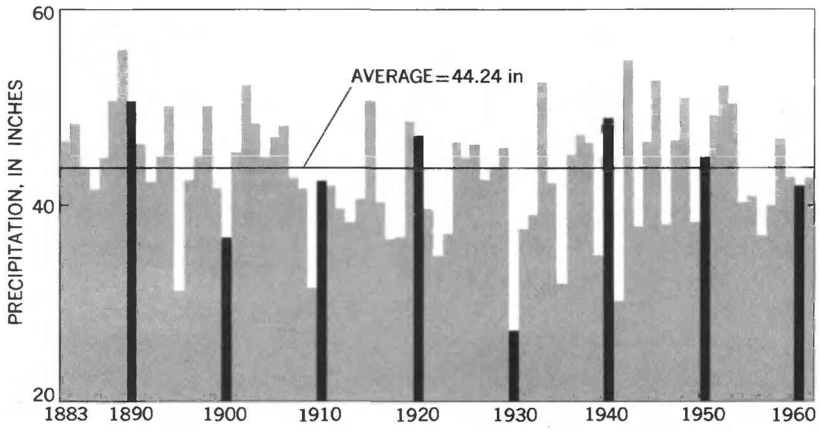

FIGURE 5.—Annual precipitation at Lebanon, 1883–1961. Data from U.S. Weather Bureau.

Zonal Patterns of Water Resources

The Swatara Creek basin is made up of eight hydrologic zones, delineated on the basis of physical characteristics which govern the hydrology of each zone. Characteristics are similar within each zone, but differ widely from characteristics of other zones. The boundaries of these hydrologic zones generally coincide with the boundaries of geologic formations. (See pl. 1*A*.)

Zones 1 through 4, in the part of the basin lying in the valley and ridge area, are underlain by sandstone and shales. The heavy forest cover in these zones consumes much water, so that the above average precipitation results in less than average stream runoff. The forest cover also inhibits flooding and erosion.

Zone 1 includes the headwaters of Swatara Creek where the highest altitude of 1,700 feet is in the southern Pocono Mountains near Tremont. Forests cover the land surface, except where open pits and piles of rock show where coal has been mined. Zone 1 is mostly a mountaintop area with approximately 15 percent of the land laid bare and subject to erosion. Large piles of waste from coal-processing plants also supply materials to be washed into the streams at every opportunity. Streams draining from coal-producing areas are acidic.

Zone 2, like zone 1, has many ridges with valleys between them, but the valleys are eroded more deeply. Only about 8 percent of the land in this zone has been mined, and most of this has been done by open-pit or strip-mining methods. Like zone 1, this zone also has large piles of erodible coal waste and rock. Many of the underground mines of zone 1 have underground connections to mines of zone 2 which provide gravity drainage of the acid mine water to lower outlets in zone 2.

Zone 3 also is in the valley and ridge area and includes part of the area west of Swatara Creek at Pine Grove and north of Blue Mountain. The land is mostly in forest except for some farmlands in the valley bottoms along Manada Creek and Trout Run. There is no coal mining in this zone. Precipitation is slightly higher in zone 3 than in zone 1, but the annual surface runoff is about the same. The low base flow from zone 3 is smaller in zones 1 and 2, probably because of the higher consumptive use of water by the forest cover.

Zone 4 is the eastern extension of zone 3 and is east of Pine Grove and north of Blue Mountain. The land is largely in forest, but the percentage in agriculture is much greater than in zone 3 because the valleys of the Upper and Lower Little Swatara Creeks are much wider than those of the tributaries in zone 3. Of the four zones in the valley and ridge area, zone 4 receives the most annual precipitation and has highest average runoff, the least water use by vegetation, and the lowest base flow. Agriculture in the valleys reduces the water use below that which would occur if the land were all in forest.

Zones 5 and 6 are in the northern part of the Lebanon Plateau. The Martinsburg Shale (composed of shales and slates) underlies both zones. Data of the Pennsylvania Geological Survey indicate the eastern part of this formation to be more sandy than the western part. Because of the less permeable shales and slates underlying these zones, flood peaks are probably higher in both zones 5 and 6 than in zone 1 to 4.

Zone 5 is the western part of the Lebanon Plateau. About two-thirds of the land is in agriculture, 15 percent in pasture and range, and 10 percent in urban development.

Zone 6 is the eastern part of the Lebanon Plateau. About three-fourths of the land is in agriculture, 15 percent in pasture and range, and 2 percent in urban development.

Zone 7 includes the southern part of the Lebanon Plateau that is underlain by limestone. Some of the limestones are porous and lend themselves readily to solution, whereas others are relatively impermeable. Where streams flow over the porous Ontelaunee and Stonehenge Formations, losses to the ground are large. Where porous formations abut the impermeable Epler Formation, the ground water is forced to the surface in the form of springs. Thus, in this zone the flow in such streams as the Quittapahilla and Spring Creeks may disappear and then reappear within a few miles. Limestone quarries pump large quantities of ground water, and some quarries dispose of the water to a stream channel, but others return the water through abandoned quarries to the ground-water system.

Zone 8 in the southern part of the basin is underlain by shales, conglomeratic sandstones, limestones, and many intruded diabase dikes of Triassic age. The land cover is forested and agricultural.

Yields of Basin

Of the 45.5 inches of precipitation that falls on the Swatara Creek basin each year, about one-half—23.0 inches—leaves the basin as streamflow into the Susquehanna River. This is equivalent to 1.1 mgd from each square mile of area in the basin. The difference—22.5 inches per year—represents the consumptive use of water in the basin, a use not easily managed by man. Consumptive use is the water lost in transit through the basin and is calculated as the arithmetic difference between rainfall on the area and runoff to the streams.

Consumptive use of water for the drainage basin above Harper Tavern, based on the period 1921–60, is 23.17 inches annually, or 1.10 mgd per sq mi. In this computation for the 40-year period, changes in soil moisture, recharge, and ground-water storage were assumed to be negligible.

For the eight zones in the basin, the average consumptive use per year is computed as follows:

Consumptive use	1	2	3	4	5	6	7	8
In. per sq mi	24.6	24.9	24.9	23.2	20.8	21.9	21.0	20.8
Mgd per sq mi	1.17	1.18	1.18	1.10	0.99	1.04	1.00	0.99

The variations in consumptive use in the year is dependent on many factors, the most important of which is the evapotranspiration use of the vegetation. Since no data on rates of evapotranspiration in the basin are available, empirical methods have been used for estimating the water use by vegetation. These methods indicate the annual use ranges from 26 to 28 inches annually. By use of the precipitation-evaporation indices of Munson (1962), the monthly water use, in inches, for Harrisburg and for Lebanon is computed as follows:

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
Harrisburg	0.30	0.52	1.22	2.16	3.56	4.29	5.13	4.48	3.12	1.95	1.01	0.48	28.22
Lebanon	.27	.46	1.16	2.13	3.48	4.20	5.13	4.48	3.08	1.94	.98	.44	27.75

On the basis of use of water by crops only during the growing season of mid-April to mid-October, the annual use for Harrisburg is about 23.3 inches and for Lebanon, 23.1 inches. Comparisons with values for areas outside the basin indicate that the use decreases about 1 inch annually for each 500 feet increase in altitude.

The comparison of monthly precipitation and water use by vegetation as shown in figure 6 indicates an annual cycle of water replenishment and water use that causes a variable monthly runoff to the streams. However, the analogy among the factors is not as simple as appears in the figure. The relation of precipitation to runoff, soil moisture, and recharge depends largely on seasonal temperatures, growth of vegetation, levels of the ground-water table, and intensity and frequency of precipitation. The needs of the vegetation are met from precipitation; and when precipitation is deficient, from depletion of the soil moisture and ground water. The replenishment of soil moisture and ground-water losses do not begin until late September when the growing season ends and precipitation exceeds the demands of the vegetation. During the winter, snow lies on the ground, and moisture added slowly to the soil recharges the ground-water reservoirs. In the spring, snowmelt and surplus precipitation recharges soil moisture and ground-water aquifers more effectively than during the winter, and the excess becomes runoff. This cycle is not uniform everywhere in the basin; for example, during the summer, water use by vegetation exceeds precipitation at Harrisburg, but not in the area above Harper Tavern. The difference is largely due to summer precipitation being higher above Harper Tavern than at Harrisburg.

Streamflow

Swatara Creek empties annually an average of 1.1 mgd per sq mi into the Susquehanna River, but yields from various parts of the basin generally range from 0.97 to 1.2 mgd per sq mi. These variations are the result of differences in such natural control factors as geology and precipitation and in such cultural factors as land use, urbanization, and industrial development.

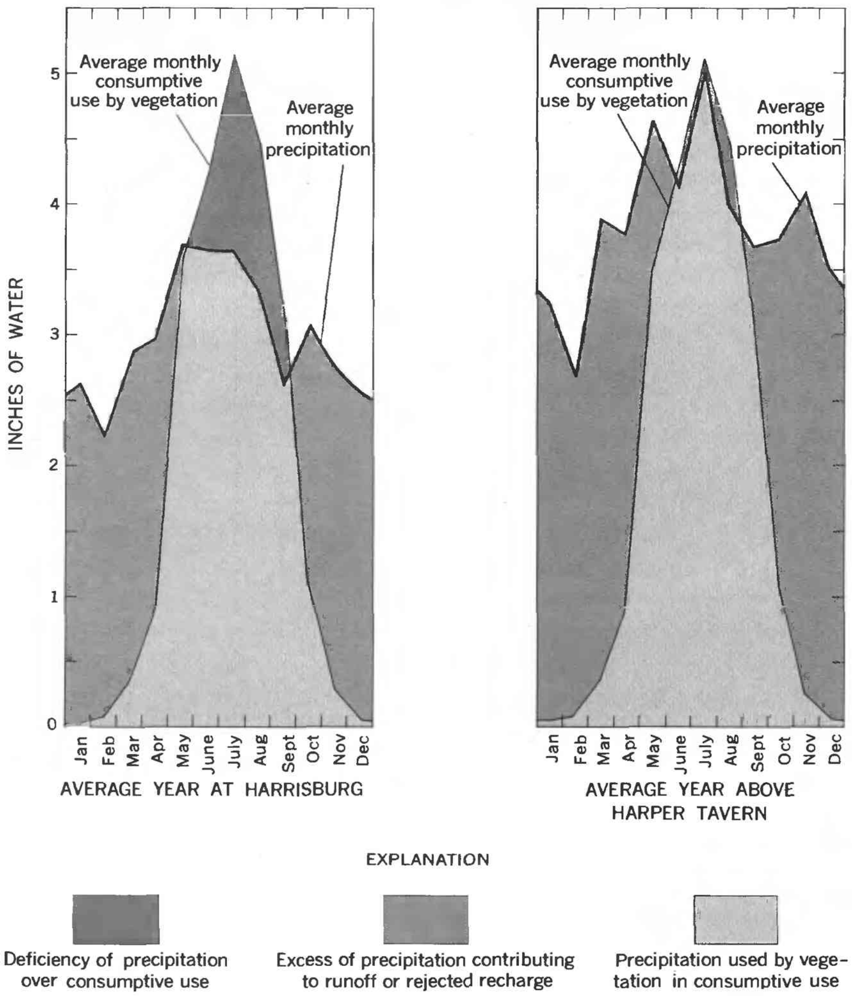

FIGURE 6.—Comparison of precipitation and monthly use of water by vegetation.

At three sites in the basin, average yields of 1.02 and 1.15 mgd per sq mi have been determined from records of streamflow. The lowest yield—1.02 mgd per sq mi—is in Manada Creek basin in the valley and ridge part of the basin, and highest yield—1.5 mgd per sq mi—is in the Little Swatara Creek basin above Pine Grove. Swatara Creek at Harper Tavern—an integration of flows from tributaries of several hydrologic zones—averages 1.10 mgd per sq mi.

Annual yields for the rest of the basin have been determined from the relation between rainfall and runoff at these three sites, and adjusted for differences in consumptive water use. The annual yield for each of the eight hydrologic zones is shown on plate 2*A*.

In zone 1 annual yields average between 1.03 and 1.1 mgd per sq mi. Although precipitation—about 47 inches—is above the basin average, the high evapotranspiration demands of forest cover reduce the annual water yield. Mine drainage, which augments low-flow of the streams in this zone, probably has little effect on yield other than to moderate the flow during the year. The area of lowest annual yields—0.97 to 1.03 mgd per sq mi—is zone 2. Zone 3, averages 1.03 to 1.10 mgd per sq mi, whereas zone 4 has a higher range—1.13 to 1.22 mgd per sq mi. Differences between zones 3 and 4 are primarily caused by differences in precipitation and land use. The cell of high precipitation over Blue Mountain (see fig. 4) and the extensive valley without forest cover east of Pine Grove increase runoff from zone 4.

Zones 5 and 6 average yields of 1.10 to 1.16 mgd per sq mi, and zone 7 from 1.03 to 1.16 mgd per sq mi. The greater variability in zone 7 is caused by solution channels in the limestone which readily divert water from one subarea to another. In general, the lower streamflow yields in zone 7 are in the central part of the zone underlain by highly permeable limestones of the Ontelaunee Formation.

Yields from zone 8 are affected by heavy evapotranspiration losses from the forest cover and range from 1.03 to 1.10 mgd per sq mi.

Ground Water

The availability of ground water in the basin is determined by the thickness, composition, and geologic structure of the underlying rocks. Because of the complexity of these factors, the availability of water at a given site generally cannot be reliably predicted on the basis of nearby wells. However, on the basis of characteristics of the rocks, the basin can be divided into four general classes for yields of wells. The highest, or excellent, classification includes those rocks in which wells yield 300 gpm or more and generally yield at least 25 gpm per foot of drawdown. The intermediate class of rocks are those in which wells yield 50 to 300 gpm and generally yield at least 5 gpm per foot of drawdown. The third, or poor, classification of rocks are those in which wells yield 10 to 50 gpm and generally yield at least 2 gpm per foot of drawdown. The fourth, or very poor, classification of rocks are those in which wells yield less than 10 gpm and yield less than 1 gpm per foot of drawdown. The geologic names of the formations in the basin, tabulated according to their classification, are listed in table 4. Their distribution is shown on plate 1*A*, *B*.

TABLE 4.—*Classification of rock units as to water-yielding characteristics*

Age	Excellent	Intermediate	Poor	Very poor
Pleistocene	Unconsolidated alluvium.			
Triassic				Diabase.
			Gettysburg Shale	
Carboniferous: Pennsylvanian		Post-Pottsville rocks.		
		Pottsville Formation.		
Mississippian			Mauch Chunk Formation.	
				Pocono Formation.
			Catskill Formation (upper part).	
Devonian			Catskill Formation (lower part).	
			Marine beds	
			Hamilton Group	
			Onondaga Limestone.	
			Oriskany Group	
			Helderberg Group	
Silurian			Bloomsburg Red Beds.	
			McKenzie Formation.	
				Clinton Formation.
				Tuscarora Sandstone.
Ordovician			Martinsburg Shale.	
				Hershey Limestone.
	Myerstown Limestone.			
	St. Paul Group			
	Annville Limestone.			
	Ontelaunee Formation.			
				Epler Formation.
		Rickenbach Dolomite.		
	Stonehenge Limestone.			
Cambrian				Richland Formation.
	Schaefferstown Formation.			
	Millbach Formation.			
		Snitz Creek Formation.		
		Buffalo Springs Formation.		

The yield of wells in limestone—the predominant rock type in zone 7—is variable. The occurrence, size, and depth of solution channels which carry most of the water, cannot be determined from the surface by geological methods. If a well does not penetrate a solution channel, it will yield little or no water. A well in limestone at another location, perhaps only a few feet away, however, may yield abundant water. Production up to 100 gpm may be obtained from larger wells that penetrate several large solution channels. Wells that do not penetrate solution channels in the upper 350 feet of limestone rarely prove successful at greater depths.

Excellent high-yielding wells are found in the limestone belt in zone 7, north of Lebanon, Palmyra, and Hershey and south of the boundary of zones 5 and 6. In this area dry holes are scarce.

In areas underlain by other rocks, particularly sandstone, yields depend on overall porosity and transmissibility rather than on solution channels. The degrees of folding, fracturing, and weathering of the rock are also factors. The areas with wells of intermediate yields are mostly underlain by loosely cemented sandstone and limestone which have not been highly fractured and folded. In general, intermediate yields are obtained from wells less than 300 feet deep in these rocks; at some places, high yields have been obtained from wells more than 500 feet deep.

Sediment and Solutes

Materials transported by water in the basin vary in quantity in response to differences in hydrologic characteristics of the basin, and they are collectively discharged at the mouth of the Swatara Creek as the sediment (table 5) and solute yield of the basin. Because movement of ground water in and out of the basin is negligible, the amount of material transported by ground water also is negligible.

TABLE 5.—Total annual sediment yield for Swatara Creek basin

[For designation of zones and subareas, see pl. 2*E*]

Zone	Total annual yield, in tons		
	Subarea A	Subarea B	Total
1			13, 700
2	5, 520	870	6, 390
3	7, 740	1, 100	8, 840
4	9, 970	650	10, 600
5	25, 700	380	26, 100
6	53, 100	900	54, 000
7			3, 700
8			8, 560

An average of about 218,000 tons of solutes and sediments is delivered annually by Swatara Creek to the Susquehanna River; about 132,000 tons is sediment and about 86,000 tons is solute. The sediment consists of sand, silt, clay, and culm. The mean annual dissolvedsolid yield of the basin is calculated to be about 21,000 tons of sulfate, 42,000 tons of bicarbonate, 17,000 tons of calcium, 2,500 tons of magnesium, and 3,500 tons of other ions—principally sodium, potassium, chloride, and nitrate. Although the average annual yield of sediment for the basin is about 230 tons per square mile, the yield ranges from an average of about 33 tons per square mile in some zones to an average of about 600 tons per square mile in others, as shown on plate 2*E*. The annual solute yield of the basin is delivered at an average rate of approximately 150 tons per square mile. The average annual solute yield ranges from 33 to 600 tons per square mile. The distribution of similar solute yields are delineated on plate 3*E*.

A small part of the dissolved and suspended materials discharged from the basin by Swatara Creek at Middletown does not originate in the basin. Small amounts of materials are brought to the basin dissolved and absorbed in snow and rain. The concentration of these materials is estimated at about 7 ppm. This figure indicates that about 13,000 tons per year of dissolved solids is added to the basin by precipitation. About half of this—6,500 tons per year, or 11 tons per square mile—is discharged from the basin as part of the solute discharge.

Variations in Runoff

Streamflow

The annual cycle of replenishment and depletion (fig. 6) of water resources in the Swatara Creek basin, combined with daily variations in precipitation, results in daily variations in streamflow, as shown in figure 7. The total runoff of Swatara Creek at Harper Tavern was near average for both the 1956 and 1957 water years, but the pattern of daily flows differed markedly for the 2 years because of variations in precipitation.

The year 1956 was characterized by one of the lowest streamflows of record to occur during a December to January period and by one of the highest streamflows to occur during an August to September period. In contrast, 1957 contained a December to January period having an above-average streamflow and an August to September period having a below-average streamflow.

The magnitude of the variations of monthly runoff characteristics for the basin are seen in figure 8, which is based on data for Swatara Creek at Harper Tavern and is accurate only for that location. However, variations at Harper Tavern indicate the general pattern of

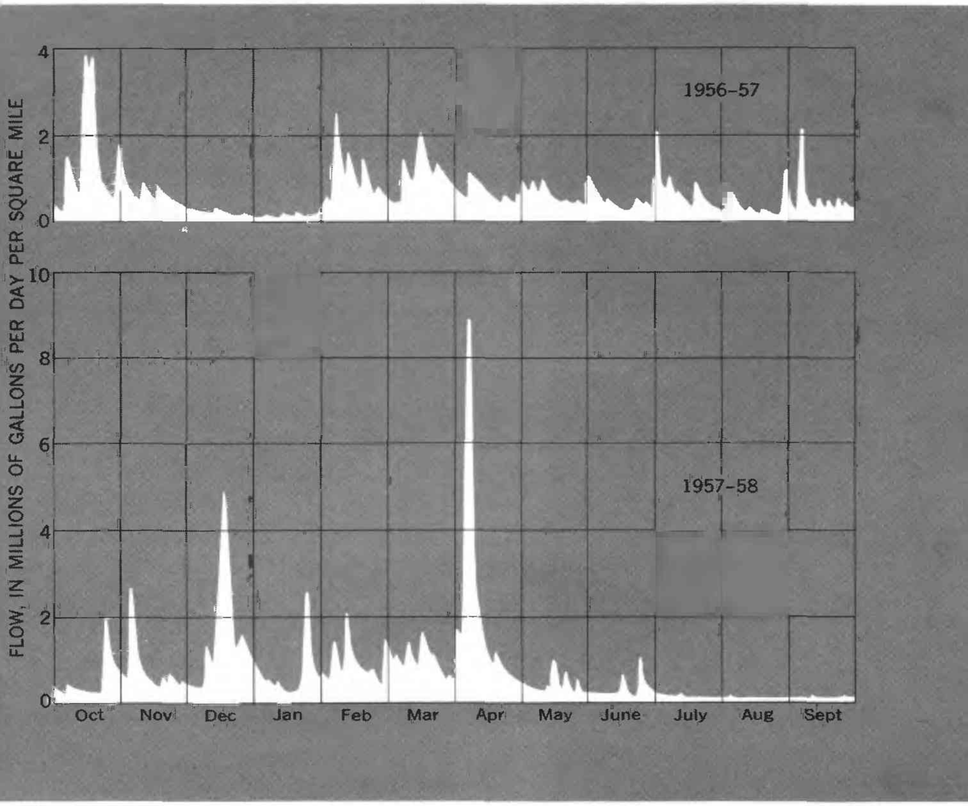

FIGURE 7.—Differences in pattern of daily streamflow, Swatara Creek at Harper Tavern for water years 1956–57 and 1957–58.

variability for a particular month and for different months which may be applicable to other parts of the basin.

The monthly flow characteristics plotted in figure 8 show the probability of flows equaling or exceeding an average flow in any given month. For example, the probability of equaling or exceeding an average flow of 1 mgd per sq mi during the month of November is 51 percent; that is, on the average, one November out of two will have a minimum average daily flow of 1 mgd per sq mi. Similarly, for November, an average daily flow of 5 mgd per sq mi or more has a probability of 5 percent, or a recurrence interval on the average of once in 20 years.

Although the average annual runoff for the Swatara Creek basin is 23 inches, the total runoff in 1932 was less than 9 inches and slightly more than 37 inches in 1952. These differences, of course, are related

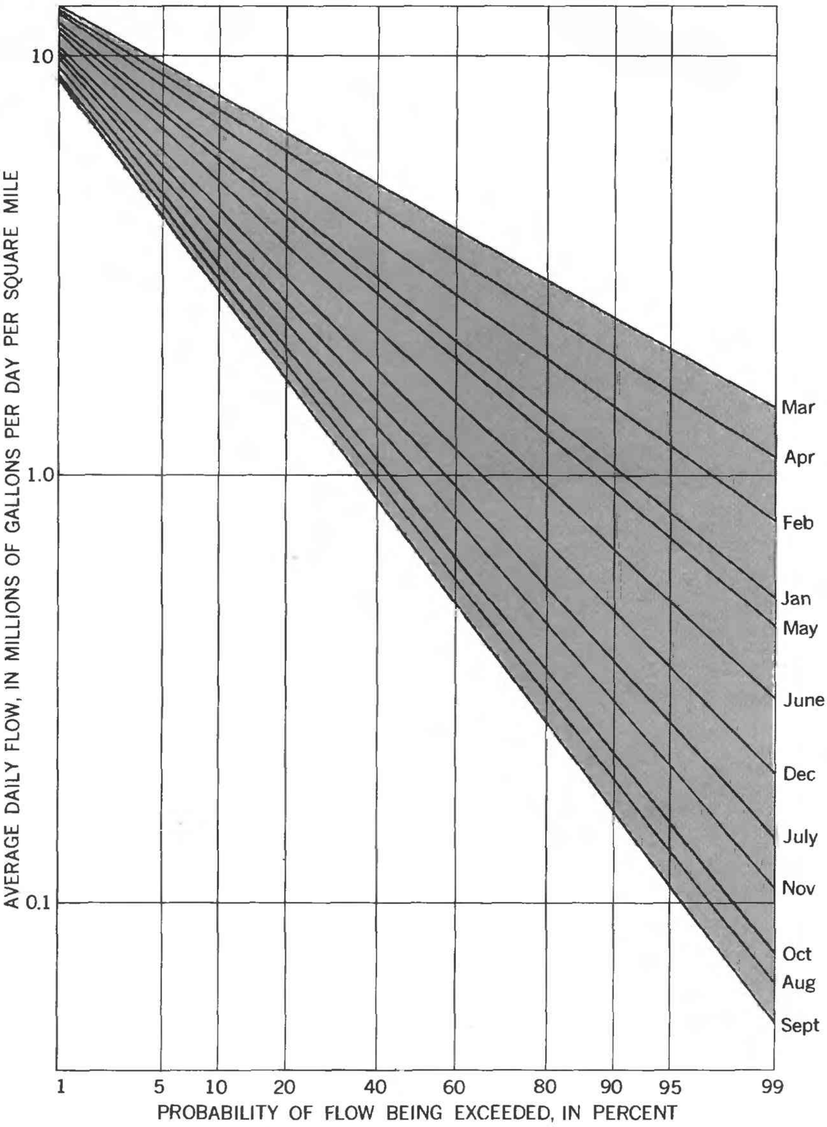

FIGURE 8.—Monthly duration of daily streamflow at Harper Tavern.

to the difference in annual precipitation. The relation between annual runoff of Swatara Creek at Harper Tavern and a weighted average of precipitation measured at Lebanon and at Pine Grove is shown in figure 9. A frequency distribution of annual runoff indicates that total runoff in 1 year out of 2 will be between 19 and 27 inches.

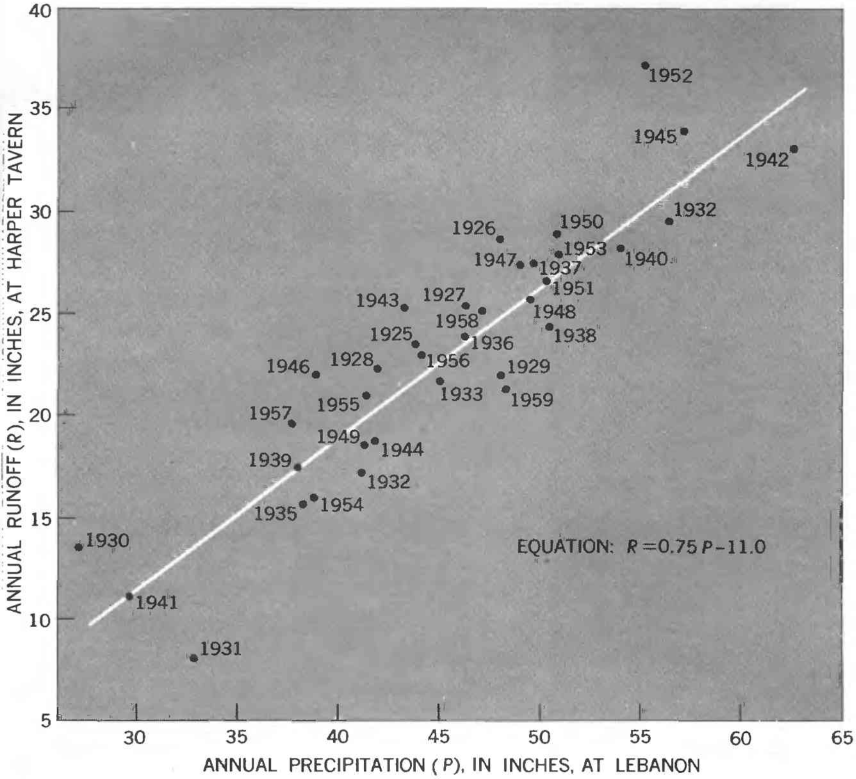

Figure 9.—Relation of runoff at Harper Tavern to precipitation at Lebanon.

A chronological sequence of annual runoff seems to indicate some tendency of groups of above-normal and below normal years to follow each other in cyclical pattern. For example, at Harper Tavern, streamflow was well below normal for the 3-year period 1930–32 and well above normal for the 4-year period 1950–53. However, statistical analyses of the data indicate no significant pattern to the sequence of annual runoff. Such groupings of several wet years or several dry years in succession are merely chance occurrences which can be expected at irregular intervals.

Ground Water

The volume of water stored in the ground of the Swatara Creek basin varies during the year in much the same manner as streamflow, and changes in ground-water storage are reflected in the rise or decline of well levels. In the Swatara Creek basin, maximum ground-water storage generally occurs in February or March and the lowest in September or October. The annual range in water levels between average spring highs and the fall lows varies greatly, from a few feet in open and porous formations to several tens of feet in slightly fractured rocks.

The water level in a well in sandstone near Pine Grove fluctuates about 10 feet during the year and that in limestone near Lebanon fluctuates about 4 feet. However, for the well at Lebanon after precipitation at any time in the nonfreezing months, the level will rise many feet rapidly and then decline to the original level just as rapidly; the entire cycle usually lasts only a few days.

Ground-water levels also vary yearly with the annual precipitation, but the variation is seldom more than several feet. This variation is observed when shallow dug wells go dry in drought years and yield water when the precipitation is normal or above.

In areas of artificial withdrawals, ground-water levels decline when any pumping occurs and rise again as soon as pumping ceases. The amount and extent of lowering depends on the rate of pumping, the volume of water in storage, and the ability of the formation to transmit water. Pumping from quarries in the Annville area to keep them unwatered to depths as great as 50 feet have lowered the levels for several square miles.

Sediment and Solutes

As water moves from one location to another, its chemical and physical characteristics vary in response to differences in geology, topography, culture, land cover, and land use and in response to changes in climatic conditions. The character of the water reflects the varied degrees of influence of each of these factors, individually or collectively. In most areas of the basin, geology and climate exert most influence; but in a few areas, industrial and domestic wastes exert an even greater influence.

Geologic formations influence the character of water because the rocks are the major source of material dissolved or carried by the water. Water acquires chemical characteristics by dissolving minerals from rocks through which it passes, either as ground water or as streamflow. In areas where rocks are homogeneous in composition, water has a characteristic type. Thus, the predominating type of water in the limestone area of zone 7 is the calcium carbonate type. In zone 8 silica content is a significant characteristic of water in contact with siliceous rocks of the environment. Sediment, a physical characteristic of water, also is derived from rocks. Relatively high concentrations of sediment in streams of zone 5 and 6 are in part due to the high erodibility of the Martinsburg Shale of these zones.

As water moves from one geologic environment to another, it acquires characteristics from each environment. The resultant mixture reflects the length of contact time between water and rocks, the solubility and erodibility of the rocks, the effect of chemical activity such as precipitation of minerals in solution, and the effect of changes in hydraulic gradient and water velocity.

In formations composed mostly of materials difficult to dissolve, such as the resistant sandstones in zones 3 and 4, the concentrations of dissolved materials in the water are low. In formations where easily dissolved rocks are predominant, the water contains high concentrations of dissolved solids. Thus, in zone 7, where limestone is the common formation, water has the highest concentrations of dissolved solids (that result from natural conditions) of all water in the basin. In zone 8, where both highly soluble limestone and slightly soluble Triassic rocks exist, the water has the greatest range in concentrations of dissolved solids of all naturally occurring water in the basin.

Land cover, land use, and topography influence the physical character of the streamflow, primarily in sediment load rather than in chemical character. For example, forested lands and lands with low relief are less prone to erosion and hence the streams have less sediment load than cultivated lands and lands with steep relief. In zones 3 and 4 the combination of resistant rocks and heavy forest cover overshadow the influence of steep topography, so that sediment yield in these zones is the lowest of the basin. Despite lesser relief in zones 5 and 6, the combination of cultivated lands and the relatively high erosion characteristics of the Martinsburg Shale makes these areas yield considerably higher quantities of sediment.

The effect of man's activities on water is readily apparent in both the chemical and the physical characteristics of water. Streams in the upper reach of the Swatara Creek basin, as recipients of coal mining wastes, are acidic and contain many more times the concentration of dissolved solids than would be expected for water draining the natural area. In other areas, such as Quittapahilla Creek and ground-water sources near Lebanon, the chemical character of the water is altered by introduction of domestic and industrial wastes. Sediment yields of zones 1 and part of zone 2, highest for the basin, are attributed to coal-mining operations, past and present. Old coal-refuse piles, culm from coal washings, and soils from fresh scarification of the land during strip-mining operations contribute large quantities of sediment to streams. In some strip-mining areas of zone 1, for example, sediment yields may exceed 15,000 tons per square mile per year as compared with a probable normal yield of about 30 tons per square mile per year for undisturbed and forested land.

Added to the variabilities in chemical and physical character of water as a result of influences of the factors described above are the effects caused by climatological changes. During periods of low stable flow when water is derived almost entirely from ground-water contributions, streams are generally free of suspended sediment and contain maximum concentrations of dissolved solids. As stream discharge increases, sediment concentrations increase markedly and concentrations of dissolved solids decrease as the streams are diluted with rainfall and overland runoff.

These variations in character follow a general pattern of dry and wet seasons in that highest concentrations of dissolved solids and lowest concentrations of suspended sediment are most common during the August to September dry season, and are the reverse during high-runoff periods of March to April. The pattern of variation is not limited to an annual cycle, however; changes occur at much more frequent intervals. Probable monthly ranges in concentration of several chemical characteristics and constituents are indicated for Swatara Creek on the calendar of chemical characteristics shown on plate 3*A*, *B*, *F*, *G*. The effect that an individual storm has on the concentrations of dissolved and suspended solids is shown in figure 10 for Swatara

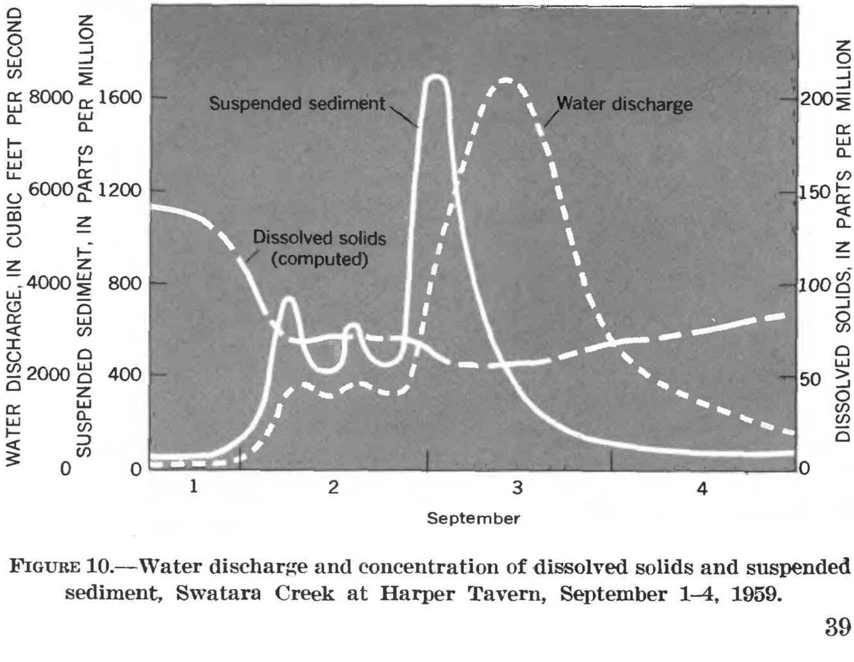

FIGURE 10.—Water discharge and concentration of dissolved solids and suspended sediment, Swatara Creek at Harper Tavern, September 1–4, 1959.

Creek at Harper Tavern during a period of storm runoff on September 2 and 3, 1959.

Long-Term Regimens

Water Budget

The long-term regimen of the water resources in Swatara Creek basin can be shown as a water budget for the area expressed as equations (all values in inches):

$$P = R_s + R_g + U_c \pm S$$

where P = average precipitation;
R_s = overland surface runoff to stream;
R_g = ground-water or base-flow runoff to the stream;
U_c = consumptive use of water in area;
S = increase (+) or decrease (−) in ground-water storage;

and

$$R_t = R_s + R_g$$

where R_t = total runoff from gaged parts of area.

The water-budget equation calculated for the 337-square-mile area of the Swatara Creek basin above Harper Tavern is shown in table 6. The values are based on a 42-year composite record and indicate the number of inches of water anually obtained from each square mile. The measured precipitation averaged 46.38 inches; the measured total runoff averaged 23.21 inches of which 11.91 inches was calculated to be surface runoff and 11.30 inches was ground-water runoff or base flow; and the consumptive use was calculated to be 23.17 inches.

These figures are based on long-term averages and are probably in the right magnitude, but they cannot be construed to be as precise as the significant figures indicate.

TABLE 6.—*Water-budget equation for Swatara Creek basin above Harper Tavern by months for average year*

[Data given in inches]

Month	*Precipitation*	=	*Surface runoff*	+	*Ground-water runoff*	+	*Consumptive use*	+	*Increase or decrease in ground-water storage*
Jan	3.22	=	1.19	+	0.98	+	0.05	+	1.00
Feb	2.68	=	1.44	+	1.06	+	.09	+	.09
Mar	3.90	=	2.16	+	1.45	+	.35	−	.06
April	3.78	=	1.70	+	1.25	+	.89	−	.06
May	4.64	=	1.29	+	1.10	+	3.48	−	1.23
June	4.15	=	0.57	+	0.76	+	4.20	−	1.38
July	5.05	=	.49	+	.74	+	5.13	−	1.31
Aug	3.99	=	.27	+	.63	+	4.48	−	1.39
Sept	3.68	=	.26	+	.61	+	3.08	−	.27
Oct	3.73	=	.27	+	.84	+	1.10	+	1.52
Nov	4.08	=	.97	+	.86	+	0.25	+	2.00
Dec	3.48	=	1.30	+	1.02	+	.07	+	1.09
Annual total	46.38	=	11.91	+	11.30	+	23.17	+	0

Streamflow

The variability in the overall regimen of streamflow is most easily shown as a cumulative frequency curve constructed on the basis of the amount of time during which specific quantities of streamflow were equaled or exceeded. This type of curve, called a flow-duration curve, indicates the magnitude of flow throughout the period of available data, but does not show chronological sequence. Its shape reflects the effect of geology, topography, climate, and culture.

Flow-duration curves for the eight hydrologic zones in the basin are shown on plate 2*B*. These curves were constructed from estimates of the mean annual runoff for subbasins in each zone, miscellaneous determinations of discharge, and the shapes of the flow-duration curves for the three gaged sites in the basin. The curves of the upper and lower limits of duration form an envelope that includes the range to be expected at specific locations in each zone. The two flow-duration curves derived from data at specific sites—Manada Creek at Manada Gap and Lower Little Swatara Creek near Pine Grove—are each shown with its appropriate zone. The flow-duration curve for Swatara Creek at Harper Tavern is shown separately in figure 11 because it represents a composite of the characteristics of five of the hydrologic zones above the site and includes the effects of diversions and returns of water.

The duration curves indicate the overall regimen of flow for the 40-year period 1921–60, and therefore show its long-term characteristics. They should not be interpreted to apply to any 1-year period, nor do they apply to small subareas in a zone where flows are altered seriously by the action of man.

The shape and position of the duration curve indicate the influence that geology, topography, and precipitation have on the hydrologic regimen of the stream. Steeply inclined curves indicate high topographic slopes with little or no channel or ground-water storage. Less steeply inclined curves indicate a higher retention of flood water as channel storage or as storage of ground water in the rocks of the basin, and a gradual release later to the base flow of the stream. Effects of higher precipitation are to shift the curve upward and lower precipitation, to shift it downward. Bending of the duration curve with less slope to the right indicates release of ground water to the base flow of the stream in increasing proportions. Bending of the duration curve with increasing downward slope to the right indicates the

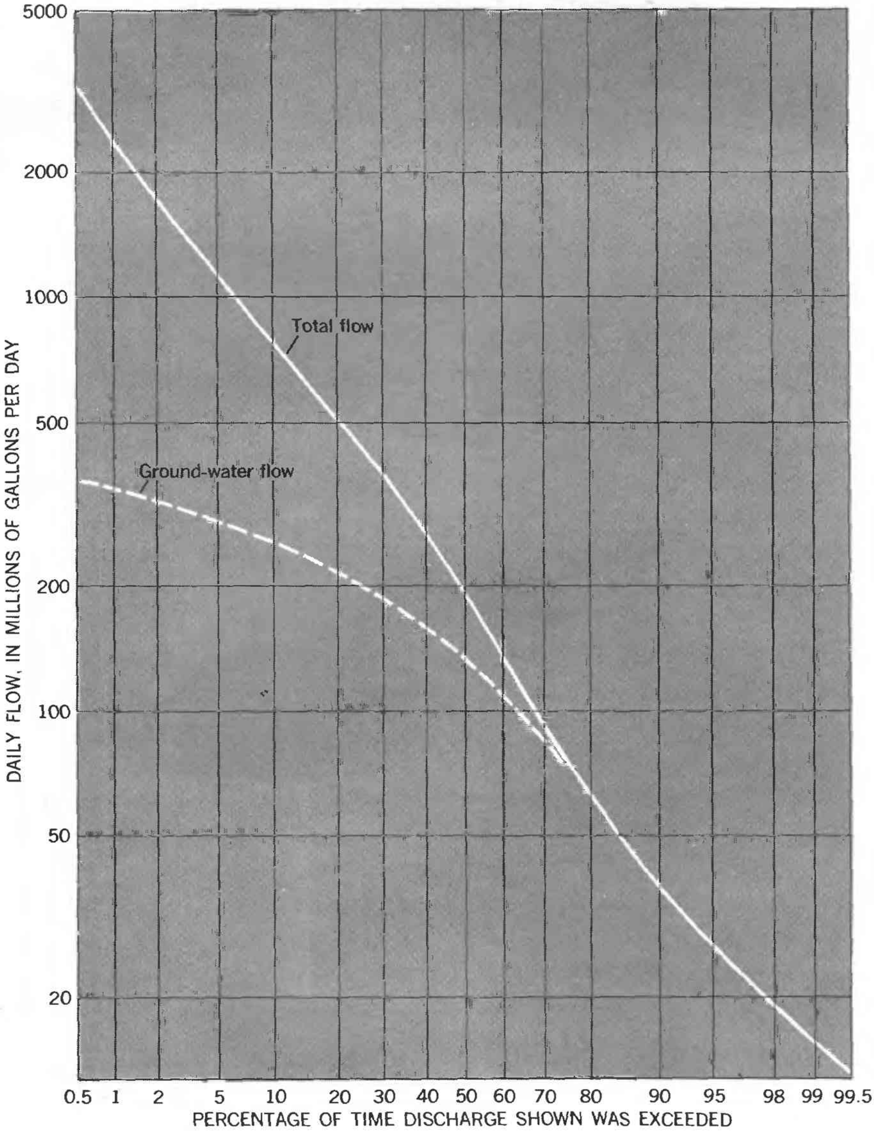

FIGURE 11.—Duration of daily streamflow, Swatara Creek at Harper Tavern, 1920–60.

release of ground water to the base flow of stream in decreasing amounts.

The duration curves of zones 1, 2, and 3 shown on plate 2*B* indicate similar hydrologic regimens of geology, topography, and ground-water storage characteristics. Although zone 4 is generally similar to the zones 1 through 3, the wide valley bottom, which lies on shales having low permeability, limits the ground-water discharge to the streams; and the duration curve for this zone reflects this restriction in the lower ranges of discharge. The steep dropoff of the lower ends of curves for zones 5 and 6 reflect the inability of the shales of the Martinsburg Shale to yield ground water to streams. The duration curve for zone 7 shows a wide range of low discharges. This is usual for limestone areas, where streamflow may vary widely within short distances. In fact, in some reaches of streams in this zone—particularly the upper reaches of Snitz, Beck, Bachman, and Killinger Creeks—actual losses of streamflow occur where flow enters the ground through fissures and solution channels in the rock. Most of this flow, however, finds its way back to these streams in their lower reaches or directly into the Quittapahilla Creek as ground-water discharge to the stream. In zone 8, yields of base flow are rather high as a result of high permeabilities and large storage capacities of the rocks in this zone.

Ground Water

The long-term ground-water regimen is indicated by the water budget. The lowest ground-water runoff of 0.61 inches per square mile, or 0.35 mgd, occurs in September when the ground-water levels are the lowest for the year. The highest ground-water runoff of 1.45 inches per square mile, or 0.81 mgd, occurs in March after the ground-water levels have reached the highest point during the year in February. The water equations also indicate that the average ground-water discharge to the stream exceeds the average overland surface runoff for each month from June through October, although in any particular month the surface runoff may greatly exceed the ground-water discharge.

The ground-water discharge to the base flow of the streams in each of the eight zones of the basin varies from month to month similarly to that for the area above Harper Tavern. The annual discharge also varies from stream to stream according to geologic conditions, precipitation, and vegetative cover. The range of average annual ground-water discharges, in millions of gallons per day per square mile, to streams in each of the eight zones is as follows: Zone 1, 0.50–0.44; zone 2, 0.49–0.37; zone 3, 0.47–0.41; zone 4, 0.44–0.32; zone 5, 0.38–0.32; zone 6, 0.39–0.35; zone 7, 0.60–0.41, zone 8, 0.60–0.54. These data were computed from analyses of recession hydrographs, empirical formulas for ground-water discharge, and flow-duration data.

Sediment and Solutes

The probable range and frequency of concentration of solutes in streams in the Swatara Creek basin are shown on plate 3*D*. The curves were drawn on the basis of relations between stream discharge and concentrations of material in the water. They show a range within which the maximum concentration of dissolved solids (as indicated by conductance) can be expected for a stream in the indicated zone. Conductance, as an approximate measure of dissolved solids, is used in this figure to represent the variability of chemical characteristics of streams, by zones, in the basin. From the curves and formulas provided with the curves, approximate values of dissolved solids and hardness and the frequency at which these values probably occur in the streams may be determined. Sulfate may be similarly defined for streams in zones 1 and 2. Other characteristics, including sulfate in zones 3 through 8, do not have a definable correlation with conductance. For these characteristics, values of probable ranges of concentrations are included on plate 3*D*.

The duration curves shown on plate 3*D* apply to streams that drain one zone. Streams that drain more than one zone, such as Manada Creek, acquire characteristics of each zone through which they pass. Determination of the chemical characteristics of these streams require definition of the proportionate amount of influence exerted by each zone. These characteristics may be computed on the basis of correlation between unit discharge and conductance.

The range of dissolved-solids concentration is smaller in ground water than in surface water. In Swatara Creek basin concentrations of dissolved solids in ground water is comparable, by zones, to surface water at the 90- to 95-percent occurrence level of conductance shown on plate 2*B*. Uncontaminated ground water in zones 1 and 2, however, is similar to ground water in zones 3 and 4. Anomalies exist in some areas as a result of man's activities or because a geologic formation at a particular site differs from the general surroundings. For example, water in Beaver Creek (in zone 5) contains larger amounts of dissolved solids than most streams in zones 5 and 6 because of septic-tank effluent. Wells in zones 5 and 6 that penetrate isolated limestone deposits will produce water that is more typical of zone 7.

Meager information also prevents better definition of some areas. This is particularly true of the chemical characteristics of zone 8, which are based on four samples. Because of the lithologies of this zone, additional data could be used to delineate areas in this zone with widely different amounts of solutes in the waters.

Sediment also is a highly variable but predictable characteristic of water in the Swatara Creek basin. Concentrations of suspended sediment may range from 0 to more than 100,000 ppm in many streams, depending on geologic, topographic, and cultural influences. Lowest concentrations occur in streams draining forested areas of the valley and ridge part of the basin; highest concentrations occur in streams that drain the coal-mining areas in the northern part of the basin.

Duration curves of suspended-sediment concentration of streams have been synthesized for erosion zones of the basin shown on plate 2*D* and *F*. The curves represent average values of the specified zones and are general estimates of the most probable values. Higher or lower concentrations of sediment will occur in streams draining small areas in which a single factor such as mining wastes, culm piles, road construction, or forest cover is a greater controlling factor than the average of all controls for the zone. For example, clearing land for housing developments or strip mining for coal will cause local sediment yields considerably higher than normal.

Acid Mine Water

Mine water from active mines and abandoned mines overflowing naturally averaged 14.6 mgd in 1961 in the Swatara Creek basin. The volume discharged into the receiving streams is shown in the following table:

Stream	*Mgd*
Good Spring Creek	3.1
Lorberry Creek	2.9
Lower Rausch Creek	3.4
Middle Creek	3.4
Swatara Creek and other tributaries above Ravine	1.4
Fishing Creek	0.4

Because this 14.6 mgd of mine water contains 4.1 tons of sulfuric acid, approximately 41 mgd of water chemically similar to that of Little Swatara Creek would be needed to neutralize this acid load.

In the early 1940's when many of the underground mines were operating, the water pumped in the basin averaged about 27 mgd. However, when underground operations ceased and the mines filled with water, the mine workings still remained as collecting sumps for water which overflows at the land surface. The rate at which this overflow varies during the year ranges from about double the average annual rate in the spring runoff period to lesser amounts during the summer, fall, and winter months. Underground mining areas diminish the high spring runoff through underground storage, which releases the water at a more uniform rate through the remainder of the year.

Strip mining intercepts the surface runoff from the watershed above the mining and exposes the acid forming materials to the dissolving action of the water. If the water is not ponded in the stripping, the area of exposure and time of exposure is small and the amount of solution is small. Therefore, the amount of acid thus formed is lower than for a similar opening in the underground mine. If the water is ponded in the strip mine, conditions for solution may duplicate those found in underground workings. The amount of water from the surface strip mining per unit area is approximately equal to the unit area runoff for the valley and ridge part given elsewhere in this report. The rate and distribution of the runoff during the year is not greatly influenced by the strip mining except that perhaps the flood runoff peak may be reduced because of the interception and temporary storage of precipitation, and the base flow may be slightly increased as a result of the delayed release of the storage.

Extremes of Flow

Streamflow

Low Flows

The information on low flows in the Swatara Creek basin is based chiefly on streamflow measurements at 54 sites made on August 22–24, 1962, and on 22 additional measurements made during the fall of 1962. The series of measurements in August were made under average low-flow conditions. Discharge of Swatara Creek at Harper Tavern indicates that the flows experienced on these dates represent the minimum flows that can be expected to occur on an average of once every 2 years. A similar flow condition existed in Manada Creek at Manada Gap. The uniformity of flow conditions in the basin at this time is reflected further in the duration curves for the three gaging stations. Duration of flow at all three locations was between 94 and 95 percent. In addition, 22 measurements made on October 20–21, 1959, in the Quittapahilla basin provided information on low-flow characteristics of the limestone area.

Thus, the average low-flow values in the following discussion represent flows to which streams will recede on an average of once in 2 years. In other words, in about half of the years, the mirimum flow for the years will be greater than that indicated.

These average low flows in the Swatara Creek basin generally range from 0.005 to 0.6 mgd per sq mi for various parts of the basin. This hundredfold range strongly reflects geologic and cultural controls and, to a lesser extent, precipitation differences in the basin.

Estimates of mean low flows for various subareas also can be grouped on the basis of the eight zones previously described (see pl. 2*C*). In the extreme headwaters of the basin (zones 1 and 2) low flows range from 0.06 to 0.45 mgd per sq mi from the region of the coal-bearing formations. Data for streams in the area without augmented flows indicate that natural yields of the area range from 0.06 to 0.12 mgd per sq mi. Many streams in the region—principally Good Spring Creek, Lower Rausch Creek, and Middle Creek—have augmentation from mine-drainage which sustain streamflows up to more than three times the unaugmented flow. At Swatara Gap unaugmented flow should be about 4.2 mgd during average low-flow periods, as against a measured flow of 8.7 mgd during the average low-flow period of August 24–26, 1962. Contributing largely to measured flow were Good Spring Creek (0.44 mgd per sq mi), Lower Rausch Creek (0.28 mgd per sq mi), and Middle Creek (0.20 mgd per sq mi).

Also, in the part of the basin lying in the valley and ridge area, zones 3 and 4 show large variability of natural low flows. Although underlain by the same type of rocks, the divergence of the ridges toward the east exposes a broad valley underlain by more shaley rocks. In the broad valley (zone 4) streams yield from 0.03 to 0.09 mgd per sq mi, whereas in the narrow valley to the west (zone 3) streams yield from 0.09 to 0.13 mgd per sq mi.

In contrast to these moderate yields, streams in the area underlain by the Martinsburg Shale (zones 5 and 6) show very low yields. In the western part (zone 5), flows range from 0.01 to 0.03 mgd per sq mi and in the eastern part (zone 6), from 0.03 to 0.05 mgd per sq mi under average low-flow conditions.

In addition to the clearly defined east-west variation in low-flow yields of the Martinsburg Shale, there is also probably a north-south variation. Two factors indicate that higher flows are sustained from the northern part of the area and that extremely low yields occur from the southern part of the area. Just east of the Swatara Creek basin, the Martinsburg Shale has been mapped by the Pennsylvania Geological Survey as two phases—a sandy phase to the north and a shaley phase to the south. It is reasonable to assume that this sandy phase, with its more favorable water storage properties, also extends westward through the Swatara Creek basin. Also, on July 31, 1962, the flow was 1.87 mgd through Manada Gap at stream mile 10.4 (location 20, tables 10, 11, fig. 19). At the same time flow at stream mile 5.8 near Manadahill was 2.32 mgd and at stream mile 1.2 near the mouth was 2.45 mgd. These data indicate a gain in rate of flow of about 0.08 mgd per sq mi from the northern part of the basin and about 0.006 from the southern part.

An anomaly in the low-flow yield occurs in the western part of the Beaver Creek basin. In this area, water imported for domestic use in the urbanized areas and subsequently released through septic-tank effluent to the ground-water reservoir results in sustained base flows far exceeding those normally expected. The suburban developments of Linglestown, Paxtonia, Colonial Park, Rutherford Heights, and other subdivisions contribute sufficient recharge to ground water to increase low flows as much as 10 times those normally expected from undeveloped areas. On August 24, 1962, measured flow from the tributary entering Beaver Creek 1.0 mile above its mouth was 0.34 mgd, and flow on Beaver Creek near its mouth was 1.66 mgd. The unaugmented flows for these two areas on this date should be about 0.06 and 0.35 mgd, respectively.

Streams in the part of Swatara Creek basin underlain by limestone (zone 7) show extremely variable low-flow characteristics. Some reaches of streams show actual losses in streamflow, while others show gains exceeding 0.6 mgd per sq mi. The net effect is a range of low flows in this zone of from 0 to about 0.26 mgd per sq mi. The variations show a pattern somewhat consistent with the lithology of the limestones. Flows of 0.20 to 0.26 mgd per sq mi issue from the Triassic rocks and enter the limestone areas of the Lebanon Plateau. Three of the streams originating in the Triassic area—Spring Creek, Killinger Creek, and Bachman Run—yield an average total base flow of about 3.2 mgd from an aggregate drainage area of 14 square miles as they enter the limestone terrane. Stream losses on the limestone terrane, however, rapidly depletes this flow. Field investigations in the latter part of August 1962 showed almost complete depletion. At that time 0.13 mgd was observed near the mouth of Bachman Creek, 0.40 mgd in the main or eastern branch of Spring Creek, and the western tributary to Spring Creek and Killinger Creek above Route 422 were dry. This depletion of streamflow occurs chiefly over the Ontelauee Formation which is highly fractured and relatively permeable. However, this water again appears as effluent seepage to the Quittapahilla Creek where this formation is exposed above the denser, less permeable limestone of the Epler Formation.

Measurements made in October 1959 and April 1960 under stable base-flow conditions indicate the magnitude of this return flow. The results are shown in the following table.

Location	Flow, in mgd, on—	
	October 20–21, 1959	April 13–14, 1960
Quittapahilla Creek at mile 7.6	9.8	14.3
Inflow, Bachman Creek	1.8	8.6
Quittapahilla Creek at mile 4.9	18.7	43.3
Accretion in reach	7.1	20.4

Additional measurements made on August 23, 1962, at mile 4.9 and 11.8 on Quittapahilla Creek show a gain of 7.45 mgd from an area of 11.6 square miles.

Another factor augmenting the flow in this reach, however, is the importation of water into the area for domestic use, and subsequent discharge through septic systems to the ground-water reservoir. Annville, population 4,000, is served by a domestic water system using springs north and southeast of town as its sources of supply. Total water use for 1962 was 110 million gallons. Assuming a 10-percent consumptive use and an urban area of 0.5 square mile, 11 inches of water is added annually to the ground-water reservoir under this urban area. This is equivlent to an increase of about 25 percent in precipitation. Because of the proximity of Annville to the Quittapahilla Creek and the ground-water gradient toward the stream, about 1.3 mgd is added to the streamflow.

The effect of quarrying in the Annville Limestone alters the low-flow characteristics of the streams in the vicinity of the quarrying operations. Quarrying in Annville Limestone occurs along a rather narrow belt along the north edge of the formation from Hershey to Lebanon. The major quarries are concentrated in a 3-mile path just north and east of Annville. In 1946 pumping at one of the quarries temporarily interrupted the water supply at the Hershey Chocolate Co. by drying up streams and diverting flow from the wells. The extent of this type of pumping on surface flow was observed in Killinger Creek during the low-flow period August 22–24, 1962. During this period Killinger Creek was dry for a distance of more than 2 miles above the quarries, while just below the quarries streamflow of 4.25 mgd was almost entirely from artificial drainage of the quarries. The lack of streamflow in the reach above the quarries is a combined result of the highly fractured Annville Limestone and the lowering ground-water levels induced by industrial pumping from the formation.

There has been some speculation that the extreme low-base flows of streams in the Martinsburg Shale from Manada Creek to Indiantown Gap also are a result of the lowered ground-water levels in the Annville Limestone. This appears unlikely, however. The relatively low transmissibilities of these shales should limit the effect to a narrow band along the contact between the shales and limestone, and this effect probably does not extend sufficiently northward into the shale to have measurable influence even on the main stem of the Swatara Creek.

Discussion of low-flow phenomena of the Swatara Creek drainage system has thus far been limited to natural accretions from ground-water sources and areal influences on them. However, diversions and returns at specific points in the drainage system, chiefly for municipal and industrial use, greatly alter the regimen of flow as controlled by the geology and other local features. The effect of interbasin diversion affects all stages of the streamflow regimen but is greatest at the lower range of discharges.

The most prominent example of interbasin diversions is the municipal water-supply complex operated by the city of Lebanon. Water for the system is obtained from three sources: Rexmont and Hammer Creek, which lie outside the Swatara Creek basin to the south; High Bridge reservoir on Fishing Creek; and Swatara Creek at Jonestown. Representative drafts during low-flow periods from the three sources in August 1961 were 1.8 mgd from High Bridge, 0.2 mgd from Rexmont, and 5.0 mgd from Swatara Creek at Jonestown. Of this total of 7.0 mgd, 0.5 mgd was supplied to Palmyra, 0.3 mgd to Indiantown Gap Military Reservation, and 0.1 mgd to Bunker Hill. About 6.0 mgd is returned to Quittapahilla Creek at the sewage treatment plant at Lebanon; about 0.5 mgd is returned to Killinger Creek near its junction with Quittapahilla Creek through the Palmyra sewage treatment plant; and about 0.2 mgd is returned to Swatara Creek above Harper Tavern.

The effect of these diversions is apparent in several discharge determinations made in August 1962. On August 25, 1962, flow of Swatara Creek at mile 44.3 at Swatara Gap was measured at 17.4 mgd; at mile 38.1 at Jonestown, below the filtration plant, flow was measured at 16.7 mgd.

On Quittapahilla Creek, at mile 12.3 just above the old Lebanon sewage treatment plant, flow was measured on August 22, 1962, at 4.76 mgd and just below the treatment plant at 9.0 mgd.

The areal variations in low flow thus far considered are based on average conditions—that is, minimum flows for about half of the years will be as low or lower. Variations between years in the low-flow periods can be seen in the range of minimum daily flows of Swatara Creek at Harper Tavern and at Manada Creek at Manada Gap. At Harper Tavern, minimum daily flows during the 43-year period 1919–61 range from 5.8 mgd in 1932 to 71 mgd in 1945. At Manada Gap, for the period 1938–57, minimum daily flows ranged from 0.52 mgd in 1941 to 2.1 mgd in 1940. Figure 12 shows the average recurrence interval of the minimum daily flows at three sites in Swatara Basin. The curves of Manada Creek and for Lower Little Swatara Creek represent natural drainage; the flow of Swatara Creek is slightly affected by augmentation from mine drainage, by storage at High Bridge reservoir and Memorial Lake, and by other diversions and additions above Harper Tavern. The net effect is a reduction of flow of Swatara Creek, and the curve is therefore not typical of any region. However, the curves for Manada Creek and Lower Little Swatara Creek probably represent the upper and lower limits for the valley and ridge area. No data are available to interpret the ranges between years for other parts of the Swatara Creek basin, but based on geologic considerations and the estimated regimens of flow as shown in the flow-duration data, the lowest minimum flows which

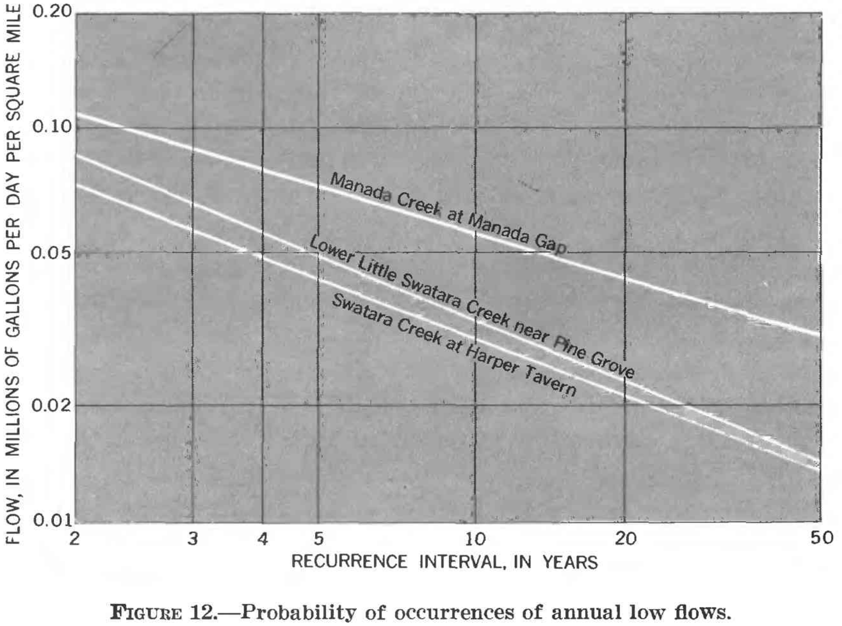

Figure 12.—Probability of occurrences of annual low flows.

might be expected probably range from about 10 to 25 percent of the indicated average low flows.

Floods

In the 42 years between 1919 and 1960, Swatara Creek spilled over its primary banks at Harper Tavern 129 times. Overbank flooding at Harper Tavern begins at about elevation 364.5 feet above mean sea level and flood stages reached an elevation of 374.21 feet during the flood of August 24, 1933. Peak discharges ranged from about 5,000 cfs (cubic feet per second) at the beginning of overbank flooding to 25,300 cfs for the 1933 flood. Historical evidence, however, indicates that a flood on June 1, 1889, reached a stage of 382.3 feet—approximately 8.2 feet higher than the 1933 flood—and produced a peak discharge of about 53,000 cfs.

Most floods occur during March, April, and May (fig. 13). This distribution is related to two factors of climate: precipitation and temperature. Although the average monthly precipitation totals are highest from May to August (fig. 14), evapotranspiration demands in the basin rise rapidly from May through July, depleting the soil moisture. The effect is an increase in the capacity of the soil to absorb rainfall and a reduction in the part of rainfall available to run off directly as streamflow. Correlatively, the high soil-moisture content in May, coupled with the high rainfall and low evapotranspiration losses, is favorable for a high incidence of flooding in May. The distribution of floods from January to March is related to temperatures as well as to precipitation. Precipitation in January and February is frequently in the form of snow, and because of the prevailing low winter temperatures in Swatara Creek basin, the snow cover persists into March. Thus, the high incidence of flooding in March—15.5 percent of all overbank floods at Harper Tavern—results from seasonal increases in temperature which release snowmelt to augment the direct runoff from rainfall.

Most spring floods result from precipitation associated with general frontal weather activity and are therefore basinwide. In contrast, most summer floods result from heavy precipitation associated with convective airmasses and thunderstorms. Because of this, summer floods are more local and more likely to affect smaller watersheds. Some evidence of this is found in a comparison of overbank flooding of Manada Creek at Manada Gap (drainage area 14.1 sq mi) with that of the Swatara Creek at Harper Tavern (drainage area 337 sq mi).

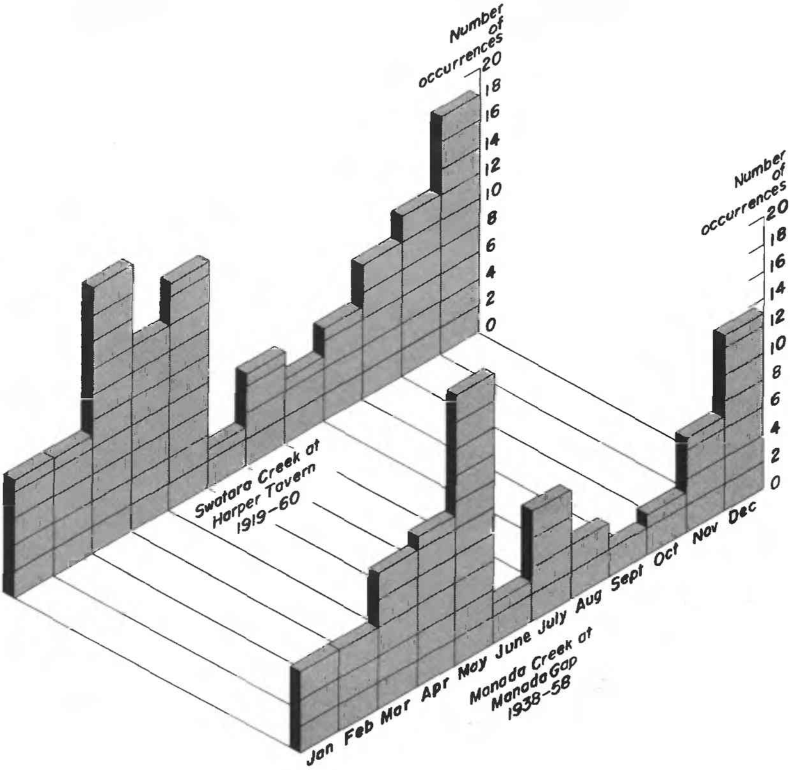

Figure 13.—Monthly distribution of overbank flooding at Harper Tavern and Manada Gap.

Thirty-two percent more floods occur on Manada Creek than on Swatara Creek during the period July through August—the period of principal thunderstorm activity.

Since 1919 flooding in Swatara Creek basin has been affected on five occasions by tropical storms originating in the Atlantic Ocean and Caribbean Sea. The paths of these storms are shown in figure 15. One of these—the tropical storm of August 1933—caused the most severe flooding on Swatara Creek since the flood of 1889. Precipitation from the 1933 storm was near record for many stations in the area; and at York, several miles south of the basin, precipitation from the storm during a 72-hour period exceeded all previous records.

The 1933 flood has a recurrence interval at Harper Tavern of about 50 years; that is, over a considerable period of time, a flood of this magnitude or greater will occur on an average of once in 50 years.

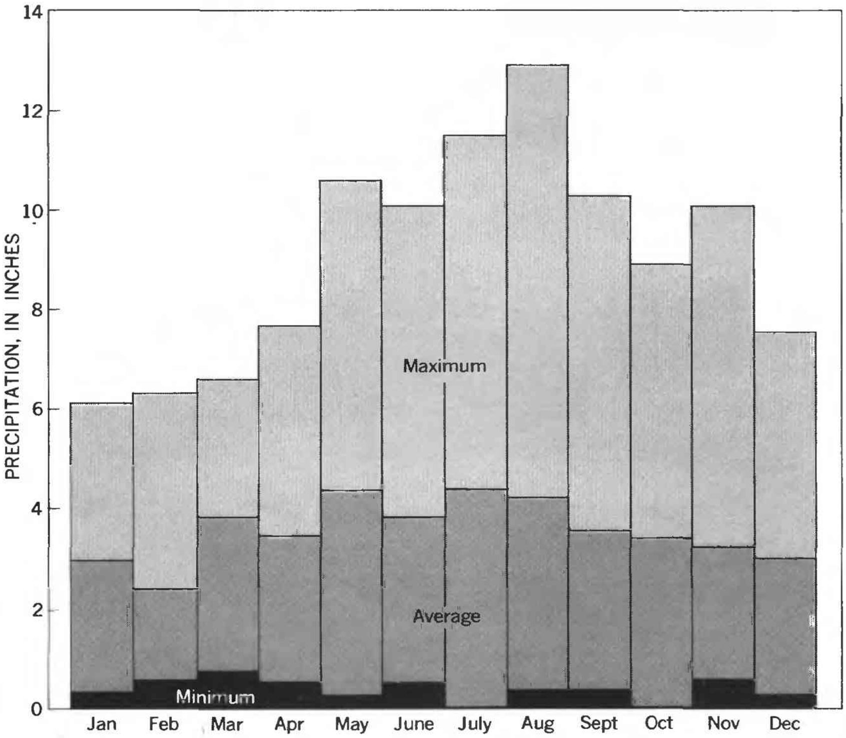

FIGURE 14.—Monthly distribution of precipitation at Lebanon.

A flood inundation map (pl. 2*F*) based on 18 recovered floodmarks indicates the extent of flooding along Swatara Creek in August 1933 from a point above Pine Grove to Middletown. The limits of inundation along the tributaries are not defined nor would a water-surface profile constructed from the 18 recovered marks define irregularities caused by local channel obstructions between floodmarks.

Sediment and Solutes

Maximum concentrations of dissolved solids and minimum concentrations of suspended materials generally occur in streams during periods of low flow. Because of the low volume of flow, the slow velocity, and the high percentage of ground water, the water in the stream is more representative of its environment, particularly geology, than at any other time. Because of these factors, water in streams during low flow generally is clear and is similar in chemical composition and concentration to ground water in the immediate environment.

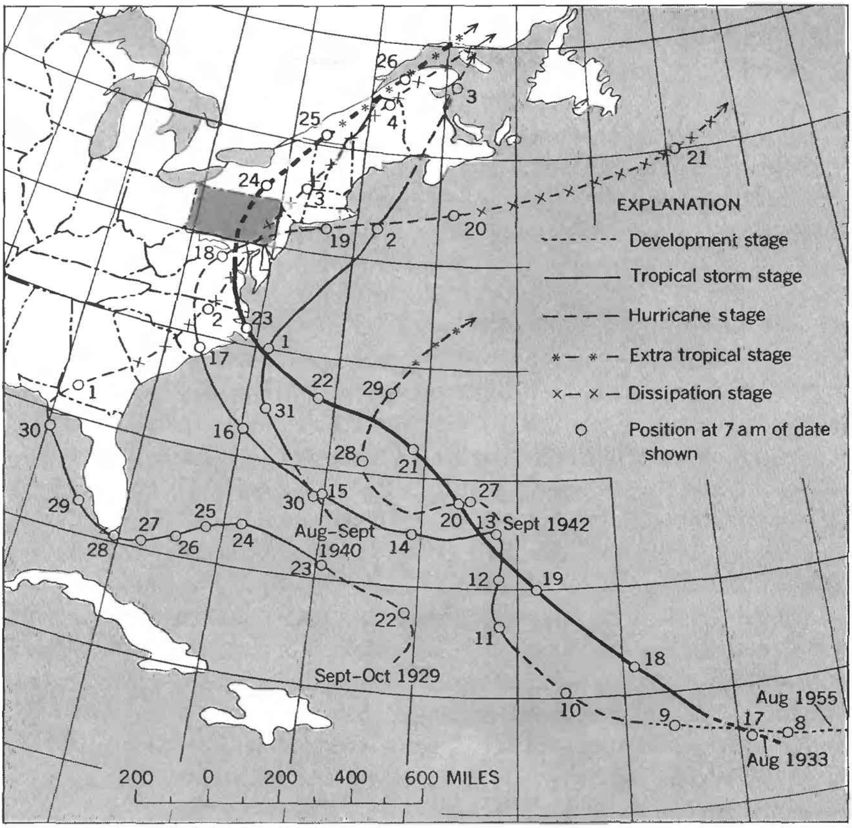

Figure 15.—Paths of tropical storms causing flooding on Swatara Creek, 1919–60.

At this time, also, anomalies in the water characteristics resulting from discharge of wastes into streams are more easily detected.

A study was made in September 1962 during low flow to determine the chemical and physical characteristics at 34 sites on streams tributary to Swatara Creek. Observations made and data obtained during this study and results of chemical analyses of samples collected previously from surface and ground sources by the U.S. Geological Survey and the Pennsylvania Department of Health during similar flow conditions were used to define the chemical characteristics of water, as shown on plate 3*C*.

Streams were generally free of suspended sediment during the study. A small amount of suspended culm was observed in Good Spring

Creek near Tremont, precipitated particles of iron oxide were observed in suspension in a turbulent reach of Lower Rausch Creek near Ravine, and suspended organic material was observed for some distance in Quittapahilla Creek below the old sewage treatment plant of Lebanon. Large flocs of detergent foam were observed on the Quittapahilla Creek below a small retention dam near Annville.

Determinations of chemical characteristics made on samples collected during the low-flow study included conductance, hardness, chloride, pH, bicarbonate, and ABS (alkyl-benzene-sulfonate, an ingredient of detergents). Determinations were also made on a few of the samples for silica, sulfate, iron, and nitrate. The results from these analyses and from chemical analyses of previously collected samples were used to delineate areas in which the chemical characteristics of the water are similar. Maximum concentrations of dissolved solids in the basin, as determined from conductance and conductance–dissolved-solids relation, occurred at Quittapahilla Creek below the Lebanon sewage treatment plant (about 700 ppm), Snitz Creek at Cornwall (about 550 ppm), Snitz Creek at Lebanon (about 500 ppm), and Lower Rausch Creek at Lorberry Junction (about 350 ppm). Minimum concentration of dissolved solids in the basin was observed at Black Creek near Tremont (about 20 ppm). Concentrations of ABS ranged from 0 to 1.2 ppm. The maximum concentration of ABS was observed on a sample obtained from Quittapahilla Creek below Lebanon. Although concentrations of ABS in excess of 0.5 ppm were noted only on samples collected from Quittapahilla Creek, samples from several stream sites contained more than 0.05 ppm, indicating a potential pollution hazard.

Anomalies in the chemical character of water were evident in several areas. Acidic and highly mineralized waters in parts of zones 1 and 2 of plate *3C* so overshadow the natural characteristics that these zones have been subdivided to represent more clearly the areas affected by mine drainage. A sulfate concentration of 334 ppm in a sample of water from Snitz Creek at Cornwall is severalfold the amount expected in water from such an environment and indicates pollution of this stream by industrial wastes.

Concentrations of dissolved solids in the sample from Quittapahilla Creek below the old Lebanon sewage treatment plant (about 700 ppm) was nearly double that of a sample (about 440 ppm) collected above the plant. In other areas anomalies are less pronounced, but differences in concentrations, above the probable normal for the area, are sufficient to indicate where water will become polluted if the trend continues. Such conditions occur in the Beaver Creek and Vesle Run basins.

Traveltime of Surface Flows

Traveltime and dispersion characteristics for a waterborne tracer in the flow of Swatara Creek between six key locations are shown in figures 16 and 17 and in tables 7 and 8. These were determined specifically for this study. Figure 16 shows the partial dispersion patterns and time of arrival for four subreaches of Swatara Creek during a time of relatively high base flow in March 1963. Streams

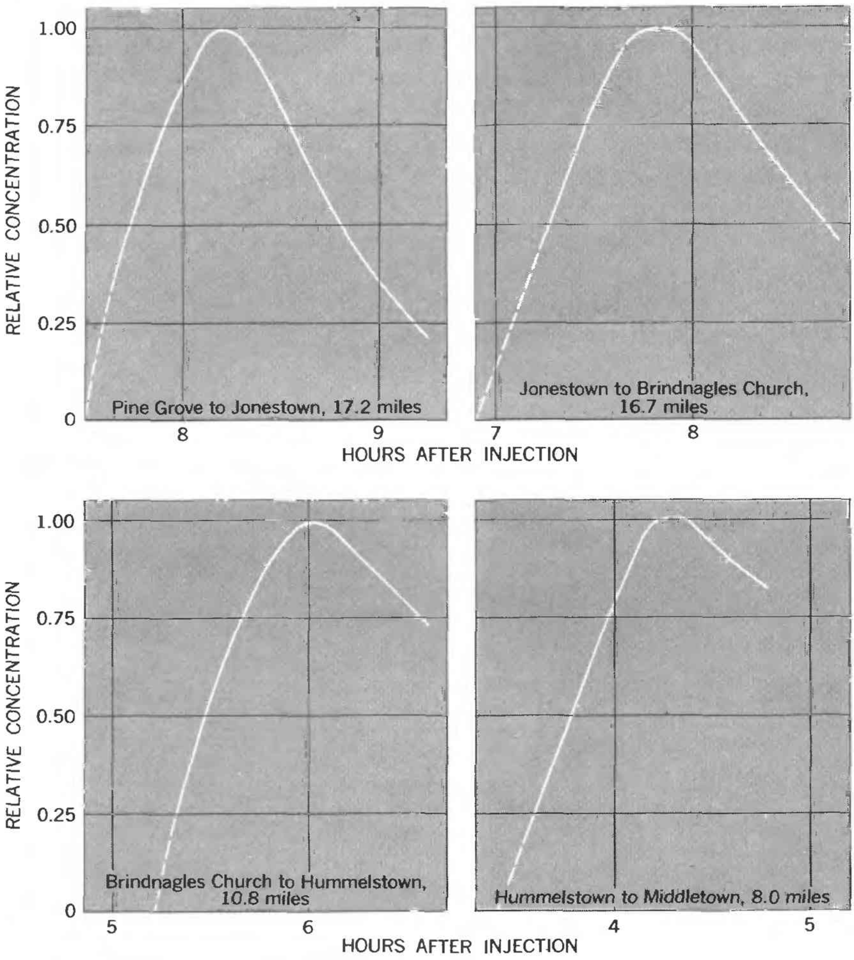

FIGURE 16.—Traveltime for water for Swatara Creek, March 20–22, 1963. The first arrival of tracer was detected at Middletown 3 hours and 25 minutes after its release at Hummelstown, 8.0 miles upstream. Maximum concentration of the tracer occurred 4 hours and 20 minutes after its release.

at the time were receding gradually from moderately high stages of the preceding week, and ground-water contributions were probably near their maximum. These data show the pattern at each site resulting from the instantaneous release of a tracer at a respective upstream location.

The traveltime and dispersion patterns at five locations as a single source of tracer released at Pine Grove travels downstream are shown in figure 17 and table 7. This study was made in May 1963 when the flow was receding following a moderate rise on the previous day. The rate of recession as the tracer moved from Jonestown to Middletown was negligible. In addition to the times of arrival at each site, relative concentrations of tracer are also shown. For example, the concentration of the peak at Hummelstown is 27 percent of the concentration of the peak at Inwood, and 71 percent of the concentration of the peak at Brindnagles Church.

Although these traveltimes apply only to the discharges shown, the traveltime between points on the Swatara Creek can be interpolated for various discharges based on data shown in figure 18. For example, the traveltime to Middletown from Pine Grove, for a flow of about 400 mgd at Pine Grove, is about 40 hours.

Traveltimes for Quittapahilla Creek are shown in table 8.

TABLE 7.—*Traveltime of a waterborne tracer on Swatara Creek, April 30 to May 3, 1963*

Location	Miles above mouth	Discharge (cfs)	Elapsed time (hours:minutes) after injection		Relative concentration of peak
			Time of 1st arrival	Time of peak concentration	
Pine Grove	55.3	[1] 300	Starting point		
Inwood	44.3	489	6:45	8:00	1.00
Jonestown	38.1	546	10:40	12:40	.84
Brindnagles Church	21.4	449	22:10	25:00	.38
Hummelstown	10.6	693	37:30	42:40	.27
Middletown	1.6	628	48:10	55:40	.21

[1] Estimated.

TABLE 8.—*Traveltime of a waterborne tracer on Quittapahilla Creek, March 20–21, 1963*

Location	Miles above mouth	Discharge (cfs)	Elapsed time (hours:minutes) after injection		Relative concentration of peak
			Time of 1st arrival	Time of peak concentration	
Above Lebanon	15.4	10.0	Starting point	0:00	
Below Lebanon	11.8	46.3	6:00	7:10	1.00
Annville	7.6	133.0	9:20	10:40	.45
Syner	2.0	233.0	[1] 15:30	17:30	.18

[1] Estimated.

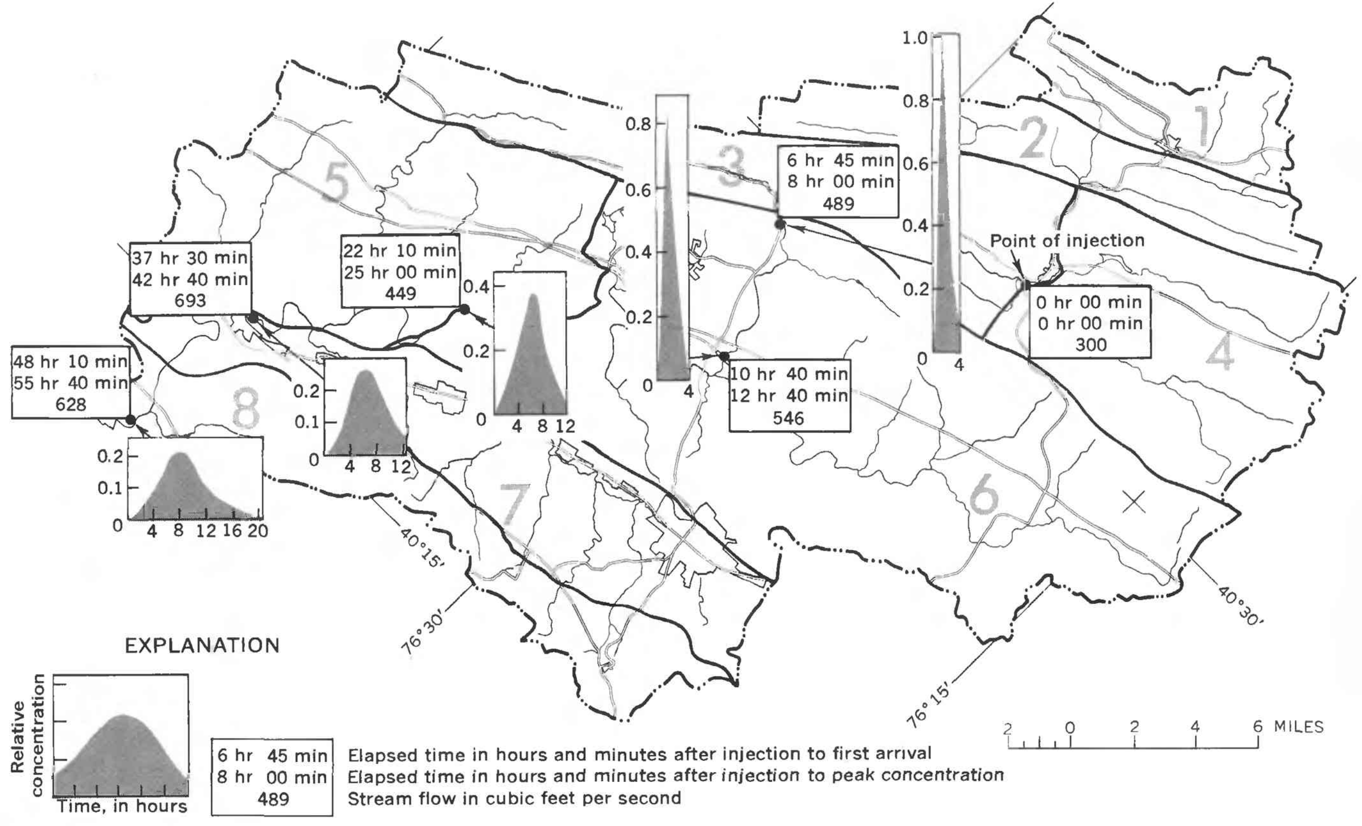

FIGURE 17.—Traveltime of water and dispersion characteristics for Swatara Creek between Pine Grove and Middletown.

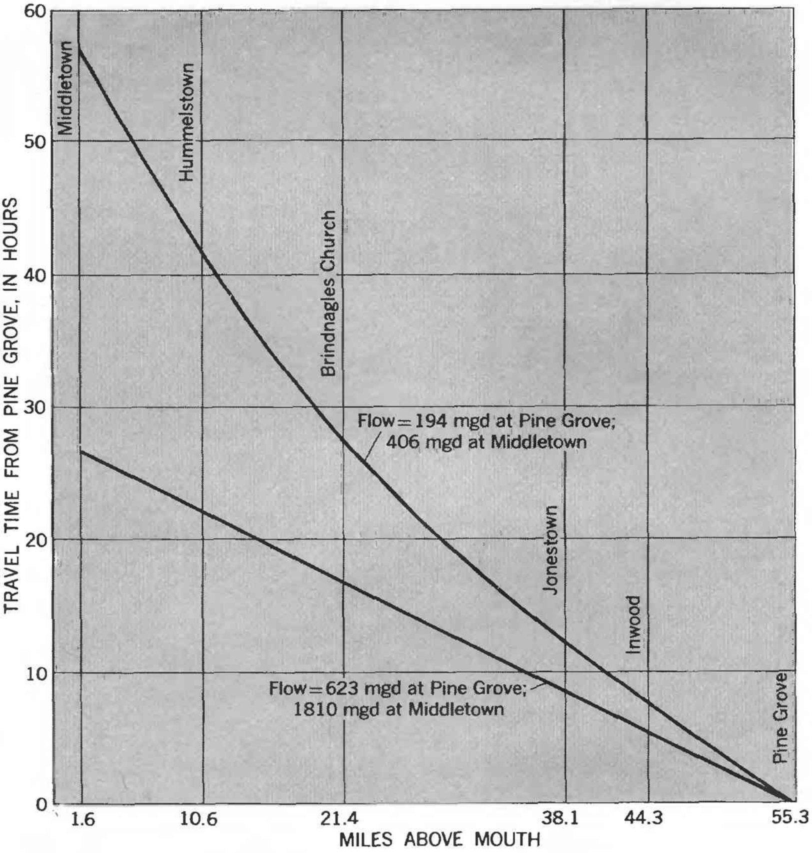

FIGURE 18.—Traveltime of peak concentration for Swatara Creek from Pine Grove to mouth.

Storage Potential

At present (1963) only a few manmade impoundments store surface water in the Swatara Creek basin. The largest is Sweet Arrow Lake on Upper Little Swatara Creek near Pine Grove. Built originally by the Pennsylvania Power and Light Co. to supply cooling water for its generating plant, the lake is now used principally for recreation. Other manmade lakes used principally for recreation include Lakes Weiss and Strause on Monroe Creek and a lake on a tributary to Trout Run at the Bashore Scout Reservation.

Lakes developed for water supplies include Lebanon Reservoir on Fishing Creek with a storage capacity of 310 million gallons. Other water-supply impoundments are on Black Creek, on Manada Creek, and on a small tributary to Swatara Creek about 4 miles below Jonestown.

The potential for additional storage in the Swatara Creek basin is excellent. The most favorable locations are in the upper part of the basin in the mountainous areas of the valley and ridge part, where the steep-sided and narrow valleys form almost ideal storage sites. Other good sites are in the rolling plains area of zones 5 and 6 which are underlain by shale. The limestone area of zone 7 is generally not well suited to surface storage because joints and solution channels would drain any surface impoundments unless they were sealed artificially and probably at great cost.

To illustrate the reservoir storage potential of the basin, three potential locations will be discussed—Swatara Creek at Inwood, draining about 160 square miles; Trout Run below Green Point, draining about 8 to 9 square miles, and Little Swatara Creek upstream from Jonestown, draining about 75 square miles. The site at Inwood was selected for hypothetical storage studies because it drains an area entirely in the valley and ridge part and also offers potential for large storage capacity. Trout Run typifies the smaller tributary drainage in the valley and ridge part, and the site on Little Swatara Creek is perhaps one of the best sites outside of the valley and ridge part.

At Inwood a storage capacity as high as 60,000 acre-feet could be developed. This is slightly more than 60 times the present storage of Lebanon Reservoir. To illustrate the possible range in development, potential storage capacities of 10,000 and 60,000 acre-feet will be considered.

A reservoir of 10,000 acre-feet would store about 5 percent of the annual flow, make a lake with about 700 acre surface area extending to about Suedberg, and could provide a steady draft of about 30 mgd. About once in 50 years almost the entire storage of 10,000 acre-feet will be depleted to maintain this draft. Each year the reservoir would fill to capacity, provided the draft rate does not exceed 45 mgd. However, a storage of 10,000 acre-feet will be insufficient to maintain this steady draft at the higher (45 mgd) rate in about one-half of the years.

A reservoir of 60,000 acre-feet, storing about 30 percent of the average annual runoff, would cover about 2,500 acres extending to Pine Grove and could provide a steady draft of more than 70 mgd. At this rate the reservoir will fail to fill and overflow in the spring on an average of only once in 40 or 50 years. Also, on an average of about once in 50 years, almost the entire storage will be depleted to maintain the 70-mgd draft.

These figures assume that the sole purpose of the storage is for water supply or low-flow augmentation. It is more likely, though, that any reservoir would be built for multiple use; that is, flood control and recreation, as well as flow augmentation, will govern the operation of release from storage. Recreational use requires that lake levels be held as near constant as possible, although fluctuations of several feet can be tolerated.

An assumed reservoir of 3,000 acre-feet capacity on Trout Run below Green Point would store about 30 percent of the average annual flow of the stream and have a surface area of about 150 acres. A steady draft of about 3.5 mgd could be provided by this reservoir.

Little Swatara Creek could provide a steady draft of about 25 mgd from a storage capacity of 15,000 acre-feet. This storage is about 15 percent of the average annual yield of the area. This reservoir would fill every year at this draft rate.

In general, the storage potential in the Swatara Creek basin, as illustrated above, represents about 30 to 40 percent of the average annual runoff.

These draft rates do not include losses by evaporation from the surface of the lakes; yearly evaporation losses are about 34 inches. Furthermore, water would be lost during the critical period when inflow to the reservoirs is at a minimum. Because these periods become critical with different draft rates, the lowering of water levels in the reservoirs due to evaporation may range from 12 to 30 inches. In general, evaporation losses will range from about 24 to 30 inches. Evaporation, of course, must be considered also in estimating safe yields, and the average rate of evaporation during critical periods when the total of evaporation and draft exceeds inflow to the reservoir must be deducted from the safe yields given above. Accurate computations of this reduction by evaporation are beyond the scope of this report; however, they could amount to slightly more than 6 mgd reduction for the larger reservoir on Swatara Creek and about 2 mgd for the reservoir on Little Swatara Creek.

A major factor to be considered in reservoir planning is the amount of sediment that passes the site each year and would be trapped by a dam. Eventually, sediments will fill any reservoir. The length of time required to do this depends on shape and capacity of the reservoir, the amount and type of sediment, and the operations of the dam. By diverting, or venting, heavy sediment flows, operators may decrease the sediment retaining ability, or trap efficiency, of the reservoir considerably.

In the Swatara Creek basin sediment is not a serious problem. Computations based on sediment yield of the drainage areas have been used to determine the probable life span of reservoirs discussed above. At Inwood sediments amount to about 35,000 tons per year. At Green Point the sediments delivered from the drainage area of Trout Run amount to about 1,100 tons per year; at Jonestown the sediments amount to about 21,400 tons per year. If the sediment is assumed to have a weight of 60 pounds per cubic foot, it is estimated that, at 100 percent trap efficiency, the reservoir at Inwood with a capacity of 10,000 acre-feet would have a life span of more than 350 years. Similarly, the life spans of the reservoirs on Trout Run (3,000 acre-ft) and Little Swatara Creek (15,000 acre-ft) would be several times greater. Better definition of the sediment loads are necessary for planning of these reservoirs. The estimates are offered only for comparative purposes and to indicate the probable relative magnitudes of sediment accretion.

The effect that impoundment of the streams would have on the water quality cannot be determined with present data. At Inwood the water will probably be slightly acidic (pH below 7.0) most of the time, culm will form a considerable part of the sediment that deposits in the reservoir, and iron and manganese residues of mine wastes and coal washings will probably be above desirable limits for many types of uses. Fish life in the form of bass, perch, and sunfish may be sustained but could be wiped out by slugs of acidic, culm-laden wastes. Water in the other reservoirs, those of Trout Run and Little Swatara Creek, would probably be suitable for most purposes.

Water Use

Approximately 56 mgd of water is used in the Swatara Creek basin for public supply, industry, domestic supply, and stock. Approximately 23 mgd is obtained from surface sources and the remainder from the ground. Even though about half of this water, 27.2 mgd, is returned to streams or the ground, demands in some areas exceed available supplies, and the water in some of these and other areas has been unfit for specific uses. As a result, in some areas, it has been necessary to obtain supplies from less accessible sources.

Public Supplies

An average of about 11.6 mgd of water was produced by 14 municipal agencies for public use in Swatara Creek basin during 1961. Approximately 85 percent, or 10 mgd, was obtained from streams in the basin. Treatment of the supplies ranged from chlorination only to chlorination, sedimentation, filtration, softening, and pH adjustment. Only one supply, obtained from ground-water sources, was not treated.

Most of the water systems obtain their supply locally, treat the water with chlorine, and deliver it with a minimum of storage. Several systems however are complex. Lebanon Municipal Water Authority controls the most complex public water system in the basin. The authority obtains a total of more than 6 mgd of water from Fishing Creek near Suedberg, Swatara Creek at Jonestown, and Hammer Creek near Rexmont, treats each supply according to the individual characteristics of the source, and delivers the water to Lebanon, other municipalities, and Indiantown Gap Military Reservation.

Hershey, which obtains its water supply from Manada and Swatara Creeks, and Pine Grove, which obtains its water supply from Black Creek and Adams Run, are other municipalities operating systems that obtain water outside of their immediate vicinity. These systems include impoundments of the streams and delivery of the water through pipes to the municipalities.

A small amount of water withdrawn from the Swatara Creek system is used outside the basin. Nearly 85 percent of the Hummelstown supply of 1.6 mgd is delivered to the Harrisburg Suburban Water Co. An estimated 1 mgd of this is distributed as public supply outside the basin. This loss is balanced to some extent, by importation of about 0.3 mgd of water from Hammer Creek by the Lebanon Authority.

Information is provided in table 9 on municipal and private agencies that produce 10,000 gpd or more of water for public use in the Swatara Creek basin.

Private Supplies

In addition to water used for public supplies, an estimated 2.0 mgd of ground water is used for domestic supplies in the Swatara Creek basin. The supplies are used by schools, by homes in rural areas, or by homes in suburban areas where municipal supplies are lacking. Information is not available on the number of these supplies that receive treatment.

TABLE 9.—*Public water supplies in Swatara Creek basin*

Location	Population served (thousands)	Owner	Source of water	Treatment	Average production 1961 (mgd)
Tremont	2.0	Tremont Water Co.	Poplar Creek, tributary to Good Spring Creek, springs.	Soda ash, calgon, chlorination.	0.190
Pine Grove	2.4	Pine Grove Bureau of Water.	Black Creek, Adams Run.	Calgon, chlorination.	.180
Joliett	.7	Mountain Water Co.	Springs, 2 wells	None	.030
Lebanon	50.0	Lebanon Municipal Water Authority.	Swatara Creek, Fishing Creek, Hammer Creek.	Alum, ammonia, chlorination, and filtration.	6.351
Campbelltown	.8	Campbelltown Water Co.	Springs	Chlorination	.030
Annville	4.2	Annville Water Co.	do	do	.297
Fredericksburg	.2	Fredericksburg Water Co.	2 wells	do	.084
Quentin	.5	Quentin Water Co.	do	do	.016
Cleona	.5	Cleona Water Co.	Spring, Lebanon Supply.	do	.013
Palmyra	.7	Palmyra Water Co.	do	do	.464
Hershey	7.5	Hershey Water Co.	Manada Creek, Swatara Creek.	Alum, lime chlorination.	1.625
Hummelstown	6.0	Hummelstown Water Co.	Swatara Creek	Filtration, soda ash, chlorination.	1.600
Linglestown	.5	Linglestown Water Co.	2 wells	Chlorination	.035
Middletown	15.0	Middletown Borough Authority.	2 wells, Iron Run, Swatara Creek.	Filtration, lime alum, chlorination.	.721
Total	76.0				11.636

An estimated 1 mgd of water is provided stock in the basin by wells, streams, and ponds. The use is nonconsumptive and causes no great stresses on the hydrologic system. Although it is preferable to provide stock with water that is acceptable for human consumption, stock will tolerate less desirable water. All water in the basin, with the possible exception of acidic waters in the upper part, is suitable for stock. Stock tolerances of acidic water is not known, but it is presumed that continued consumption of such water would be detrimental to health.

Approximately 41 mgd of water was used by 33 industries in the Swatara Creek basin during 1961. About 61 percent (25.3 mgd) was used by food-processing plants. The remainder was used for manufacturing and processing of raw materials, stone (7.9 mgd), steel (3.5 mgd), coal (2.4 mgd), and other cooling (1.8 mgd). Most of the water used by food processing plants is used for cooling and washing, and about one third is returned to the ground. About half of the water used by coal preparation plants is returned to the watershed.

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BASIC DATA

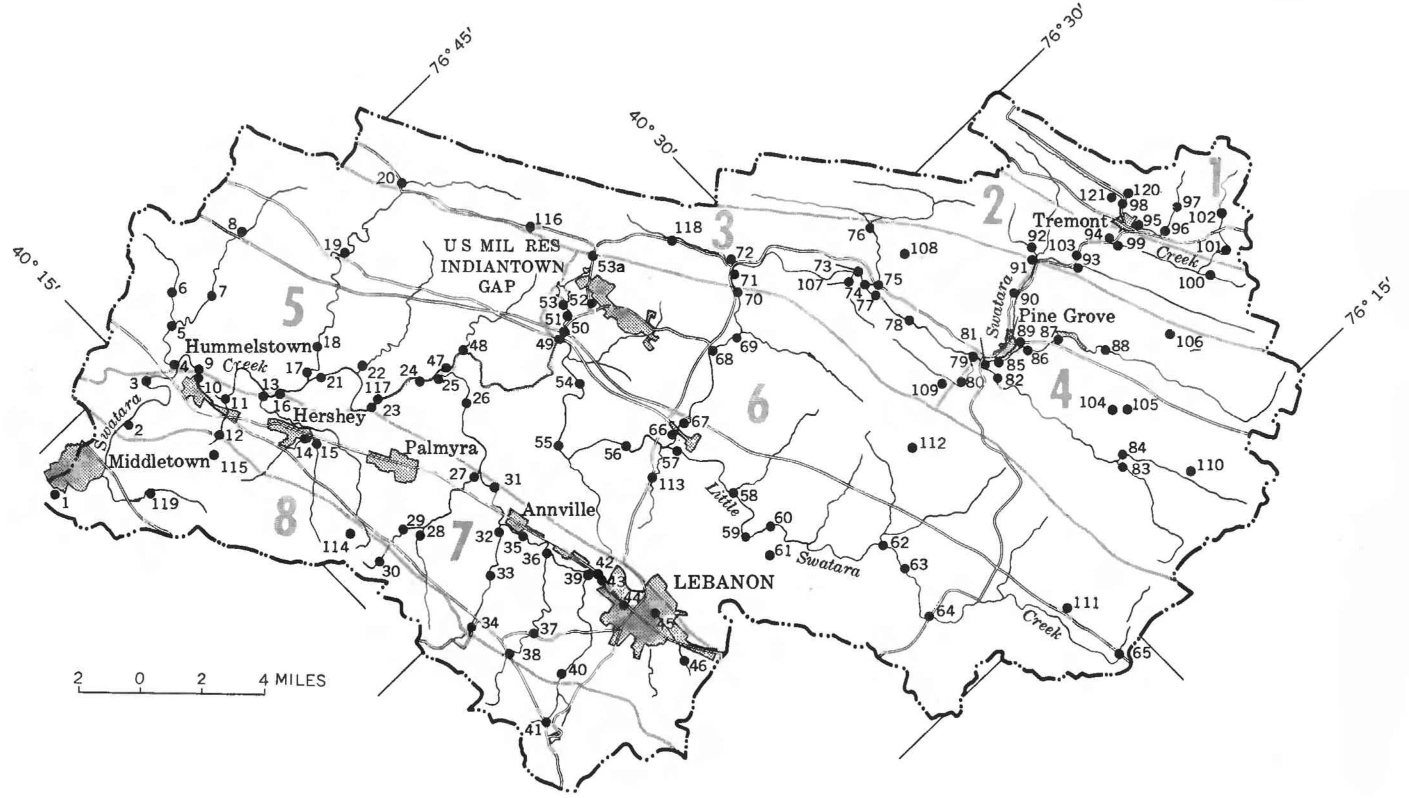

FIGURE 19.—Sites at which hydrologic data were collected for this report. Numbered sites correspond to those given in tables 10–14.

TABLE 10.—*Stream-mile locations and drainage areas for some points of hydrologic significance in the Swatara Creek basin*

[Miles above mouth: The stream-mile locations indicate distances in the mileage column with respect to the next higher order stream. For example, location 4 is 8.8 miles above the mouth of Swatara Creek. The corresponding 0.0 mile in the next column indicates the stream-mile designation Beaver Creek. Similarly, location 5 is 1.8 miles above the mouth of Beaver Creek, and the 0.0 mile in the next column indicates the stream-mile designation along Beaver Creek Tributary. Location 6 is 1.0 mile above the mouth of Beaver Creek Tributary]

Location No. (fig. 19)	Stream name and location	Drainage area (sq mi)	Miles above mouth		
1	Swatara Creek at mouth	576.00	0.0		
2	Swatara Creek, 1936 floodmark, elev 305.8 ft; 1933 flood about 305 ft		3.9		
3	Swatara Creek, 1933 floodmark, elev 322.6 ft		7.2		
4	Beaver Creek at mouth	27.00	8.8	0.0	
5	Beaver Creek Tributary at mouth			1.8	0.0
6	Beaver Creek Tributary at county bridge	5.51			1.0
7	Beaver Creek at bridge on Rt. 340	17.10		2.9	
8	Beaver Creek at county bridge	9.63		6.2	
9	Swatara Creek, 1933 floodmark, elev 331.0 ft		10.6		
10	Swatara Creek at bridge at Hummelstown		10.7		
11	Swatara Creek Tributary at mouth	3.40	11.6	.0	
12	Swatara Tributary at county bridge	1.22		1.1	
13	Spring Creek at mouth	24.30	14.0	.0	
14	Spring Creek Tributary at mouth	11.10		2.2	.0
15	Spring Creek Tributary at bridge on Rt. 422				.3
16	Swatara Creek at bridge at Union Deposit		14.1		
17	Manada Creek at mouth	31.00	15.6	.0	
18	Manada Creek at county bridge			1.2	
19	Manada Creek at county bridge			4.9	
20	Manada Creek at gaging station at Manada Gap	13.50		10.4	
21	Swatara Creek, 1933 floodmark, elev 352.3 ft		15.7		
22	Bow Creek at mouth	9.52	17.3	.0	
23	Swatara Creek, 1933 floodmark, elev 356.4 ft		19.6		
24	Swatara Creek at county bridge	438.00	21.4		
25	Quittapahilla Creek at mouth	79.90	21.6	.0	
26	Quittapahilla Creek at county bridge			2.0	
27	Killinger Creek at mouth	14.00		4.5	.0
28	Gingrich Run at mouth	5.31			3.2
29	Killinger Creek at county bridge	1.90			4.1
30	Killinger Creek at bridge on Route 820	.59			5.4
31	Quittapahilla Creek at county bridge	59.40		4.9	
32	Bachman Run at mouth			7.0	.0
33	Bachman Run at county bridge	6.80			1.9
34	Bachman Run at bridge on Route 322	3.38			3.4
35	Quittapahilla Creek at bridge on Route 934			7.6	
36	Beck Creek at mouth	7.87		9.6	.0
37	Beck Creek at bridge on Route 241	3.21			3.4
38	Beck Creek at county bridge	1.48			5.2
39	Snitz Creek at mouth	12.00		11.4	.0
40	Snitz Creek at bridge at Zinns Mill	7.37			4.2
41	Snitz Creek at bridge on Route 322	3.06			5.6
42	Quittapahilla Creek at county road	21.20		11.8	
43	do	21.00		12.3	
44	Quittapahilla Creek at Town Street			13.4	
45	do			14.0	
46	Quittapahilla Creek at county road			15.4	
47	Swatara Creek, 1933 floodmark, elev 356.7 ft		21.8		
48	Shirks Creek at mouth		23.0	.0	
49	Swatara Creek at gaging station at Harper Tavern	337.00	28.4		
	Swatara Creek, 1933 floodmark, elev 374.21 ft		28.4		
50	Indiantown Creek at mouth	11.60	28.5	.0	
51	Vestle Run at mouth			1.3	.0
52	Vestle Run at county bridge				1.0
53	Indian Creek below Memorial Lake			1.6	
53a	Indiantown Creek at Indiantown Gap			1.9	
54	Swatara Creek, 1933 floodmark, elev 378.2 ft		30.3		
55	Swatara Creek, 1933 floodmark, elev 390.2 ft		33.3		
56	Swatara Creek, 1933 floodmark, elev 398.7 ft		35.7		
57	Little Swatara Creek at mouth	99.40	37.5	.0	
58	Elizabeth Run at mouth	9.99		3.2	.0
59	Little Swatara tributary at mouth	4.96		5.1	.0
60	Deep Run at mouth	6.26		6.0	.0
61	Deep Run at county bridge				.9
62	Crosskill Creek at mouth	18.80		8.0	.0
63	Little Swatara Creek at county bridge	27.50		11.4	
64	Little Swatara Creek at bridge on Route 501			14.2	
65	Little Swatara Creek at bridge on Route 22			23.4	
66	Swatara Creek at bridge at Jonestown	193.00	38.1		

TABLE 10.—*Stream-mile locations and drainage areas for some points of hydrologic significance in the Swatara Creek basin*—Continued

Location No. (fig. 19)	Stream name and location	Drainage area (sq mi)	Miles above mouth		
67	Swatara Creek, 1933 floodmark, elev 408.5 ft		38.4		
68	Swatara Creek, 1933 floodmark, elev 423.3 ft		41.6		
69	Swatara Creek, 1933 floodmark, elev 431.2 ft		43.2		
70	Swatara Creek at bridge at Inwood Gap	169.00	44.3		
71	Swatara Creek, 1933 floodmark, elev 452.7 ft		45.3		
72	Trout Run at mouth	8.63	45.3	.0	
73	Bear Hole Run at mouth	3.17	50.0	.0	
74	Mill Creek at mouth	17.70	50.5	.0	
75	Mill Creek at bridge at Route 443			.5	
76	Mill Creek at Lebanon Reservoir			2.8	
77	Swatara Creek, 1933 floodmark, elev 478.1 ft		50.6		
78	Swatara Creek, 1933 floodmark, elev 484.7 ft		52.4		
79	Swope Valley Run at mouth	5.49	55.0	.0	
80	Swope Valley Run at county bridge	5.08		1.1	
81	Lower Little Swatara Creek at mouth	36.20	55.3	.0	
82	Lower Little Swatara Creek at gaging site at county bridge	34.30		.6	
83	Lower Little Swatara Creek tributary at mouth	8.74		6.0	.0
84	Lower Little Swatara Creek at bridge on Route 895			6.2	
85	Swatara Creek, 1933 floodmark, elev 503.2 ft		55.6		
86	Upper Little Swatara Creek at mouth		56.6	.0	
87	Upper Little Swatara Creek below Sweet Arrow Lake	20.60		1.5	
88	Upper Little Swatara Creek at county bridge	17.60		3.2	
89	Swatara Creek, 1933 floodmark, elev 515.1 ft		56.8		
90	Swatara Creek at bridge on Route 125	43.30	59.2		
91	Lower Rausch Creek at mouth	4.86	59.8	.0	
92	Lorberry Creek at mouth	3.99		.1	.0
93	Black Creek at mouth	6.89	60.9	.0	
94	Good Spring Creek at mouth	14.80	62.8	.0	
95	Middle Creek at mouth	6.50		.6	.0
96	Gebhard Run at mouth	2.00			1.2
97	Middle Creek at county bridge	2.41			2.0
98	Good Spring Creek at county bridge	6.14		1.6	
99	Swatara Creek at bridge on Route 125		63.1		
100	Panther Creek at mouth	1.78	65.9	.0	
101	Swatara Creek at county bridge	3.99	67.3		
102	Swatara Creek at Newton		69.7		

TABLE 11.—*Measurements of streamflow in Swatara Creek basin, July 1, 1962, to June 30, 1963*

Location No. (fig. 19)	Date	Discharge (cfs)	Temperature (° F)
1	Oct. 29, 1962	175	50
	Feb. 21, 1963	629	
	Mar. 1, 1963	302	
	Mar. 8, 1963	5,530	
	Mar. 14, 1963	3,910	
	May 30, 1963	628	
4	Aug. 24, 1962	2.56	64
6	do	.57	77
7	do	.52	62
8	Aug. 23, 1962	.30	64
10	Oct. 29, 1962	173	49
	Feb. 21, 1963	501	
	Mar. 1, 1963	335	
	Mar. 8, 1963	3,720	
	Mar. 14, 1963	2,780	
	May 2, 1963	693	
11	Aug. 24, 1962	.23	71
12	do	.47	64

TABLE 11.—*Measurements of streamflow in Swatara Creek basin, July 1, 1962, to June 30, 1963*—Continued

Location No. (fig. 19)	Date	Discharge (cfs)	Temperature (° F)
13	do	34.8	78
14	do	0	
15	do	.58	60
16	Oct. 29, 1962	142	48
	Feb. 21, 1963	545	
	Mar. 1, 1963	271	
	Mar. 8, 1963	3,790	
	Mar. 14, 1963	3,040	
17	July 30, 1962	.87	81
18	do	3.52	
	Aug. 2, 1962	3.15	81
	Aug. 24, 1962	.48	70
19	July 31, 1962	3.6	70
	Aug. 24, 1962	2.57	66
20	July 31, 1962	2.94	67
	Aug. 23, 1962	2.5	58
22	July 31, 1962	.44	76
	Aug. 24, 1962	.43	76
24	May 2, 1963	449	
	Oct. 29, 1962	142	47
26	Aug. 23, 1962	40.4	63
	Oct. 29, 1962	39.1	48
27	Aug. 23, 1962	6.65	60
28	Aug. 24, 1962	0	
	Sept. 26, 1962	20	
29	Aug. 23, 1962	.13	
	Sept. 24, 1962	.19	
30	Aug. 23, 1962	.26	62
31	do	30.2	65
32	Sept. 26, 1962	3.18	
33	Aug. 23, 1962	.17	60
34	Aug. 22, 1962	1.17	62
36	do	2.01	64
37	do	.55	73
38	do	.48	76
39	Aug. 23, 1962	2.47	65
40	Aug. 22, 1962	.82	66
41	do	.32	65
	Sept. 26, 1962	.76	55
42	Aug. 22, 1962	13.9	74
43	do	7.39	76
48	Aug. 24, 1962	.27	64
49	Aug. 23, 1962	46.6	76
	Oct. 29, 1962	99	46
	Feb. 21, 1963	417	
	Mar. 1, 1963	213	
	Mar. 8, 1963	2,880	
	Mar. 14, 1963	1,820	
52	Aug. 23, 1962	2.24	72
57	do	9.8	78
	Oct. 29, 1962	17.5	46
	Nov. 5, 1962	152	42
58	Aug. 22, 1962	1.5	61
59	do	.36	66
61	Aug. 1, 1962	.19	85
	Aug. 22, 1962	.24	69
63	do	1.22	68
64	do	1.89	73

TABLE 11.—*Measurements of streamflow in Swatara Creek basin, July 1, 1962, to June 30, 1963*—Continued

Location No. (fig. 19)	Date	Discharge (cfs)	Temperature (° F)
66	Aug. 23, 1962	26	68
	Oct. 29, 1962	68.5	45
	Feb. 21, 1963	379	----------
	Mar. 1, 1963	104	----------
	Mar. 8, 1963	1,620	----------
	Mar. 14, 1963	1,090	----------
	May 1, 1963	546	45
70	Aug. 23, 1962	27.1	68
	Oct. 29, 1962	68.2	48
	Feb. 21, 1963	237	----------
	Mar. 1, 1963	107	----------
	Mar. 8, 1963	934	----------
	Mar. 14, 1963	1,000	----------
	May 1, 1963	489	----------
73	Aug. 23, 1962	1.51	61
	Sept. 25, 1962	.54	53
75	Aug. 23, 1962	.49	70
76	do	1.4	70
81	do	.87	68
82	do	3.05	70
	Sept. 25, 1962	10.5	----------
83	Aug. 23, 1962	1.26	65
84	do	.38	69
85	Feb. 21, 1963	76	----------
	Mar. 1, 1963	70	----------
	Mar. 8, 1963	300	----------
	Mar. 14, 1963	348	----------
86	Aug. 23, 1962	2.44	73
	Sept. 25, 1962	3.22	50
88	Aug. 23, 1962	1.83	68
90	do	13.5	60
	Oct. 29, 1962	28.5	48
	Nov. 5, 1962	70.3	44
	Feb. 21, 1963	40	----------
	Mar. 1, 1963	32	----------
	Mar. 8, 1963	103	----------
	Mar. 14, 1963	162	----------
91	Aug. 23, 1962	2.01	58
	Sept. 24, 1962	1.14	55
92	do	2.38	55
94	Aug. 23, 1962	.85	59
98	do	.75	58
	Sept. 24, 1962	1.63	57
99	Aug. 23, 1962	4.18	58
	Sept. 24, 1962	2.95	55
	Feb. 21, 1963	15	----------
	Mar. 1, 1963	9	----------
	Mar. 8, 1963	34	----------
	Mar. 14, 1963	39	----------
101	Aug. 23, 1962	.37	62
	Oct. 29, 1962	1.05	47

TABLE 12.—*Chemical analyses of samples from streams in Swatara Creek basin, July 1, 1962, to June 30, 1963*

[Discharge: Asterisk (*) indicates estimated]

Location No. (fig. 19)	Discharge (cfs)	Date of collection	Parts per million								Specific conductance (micromhos at 25° C.)	pH
			Silica (SiO_2)	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Alkyl benzene sulfonate (ABS)	Hardness as $CaCO_3$ Calcium Magnesium		
102		3- 7-63		.05	0					92	290	4.5
101	1.05	10-29-62	9.7		0		2.0	0.2		120	316	4.5
99	3	9-24-62	13	.10	2	160	.5		0.00	160	381	5.0
	15	2-21-63			4	97				92	256	5.2
	9	3- 1-63			2	96				101	263	5.2
	34	3- 8-63			0	60				53	168	4.5
	39	3-14-63			3	58				52	164	4.7
98	1.63	9-24-62	13			193	2.5		.19	180	548	3.7
93	*.9	9-24-62	6		6	2.5	.0		.04	12	28	6.9
92	2.4	9-24-62	12	3	0	116	.5		.00	122	311	4.5
91	1.14	9-24-62			4		1.0		.00	296	607	5.1
90	*14	9-24-62		1.7	0	246	1.5		.01	210	581	3.9
	28.5	10-29-62	12		0	218	1.0			196	554	3.9
	40	2-21-63			0	134				122	354	4.25
	32	3- 1-63			0	158				140	404	4.15
	103	3- 8-63			0	94				83	259	4.3
	162	3-14-63			0	84				74	233	4.3
86	3.32	9-25-62	3.7		34	4.8	3.5		.04	34	87	7.1
85	76	2-21-63			4	72				73	210	5.2
	70	3- 1-63			2	75				76	220	5.2
	300	3- 8-63			2	45				48	149	5.0
	348	3-14-63			1	57				58	171	4.7
82	10.5	9-25-62	4.2		20	4.6	4.5		.02	25	69	7.0
75	*1.4	9-25-62	8		18	3.4	2.5		.04	16	48	6.7
70	*30	9-25-62	7.8		3	85	2.5		.03	96	235	5.1
	68.2	10-29-62	8.1		3	91	3.5			92	243	5.1
	237	2-21-63			6	44				53	158	5.9
	107	3- 1-63			4	58				61	177	5.8
	934	3- 8-63			8	21				29	94	5.9
	1,000	3-14-63			5	25				38	93	5.8
66	*30	9-25-62	7.8		8	60	3.0		.01	67	176	6.6
	67.8	10-29-62	9.9		3	83	2.5		.01	89	228	5.2
	379	2-21-63			6	42				51	162	6.4
	104	3- 1-63			8	51				57	166	6.4
	1,620	3- 8-63			6	19				28	93	5.9
	1.090	3-14-63			8	19				31	96	6.2

TABLE 12.—*Chemical analyses of samples from streams in Swatara Creek basin, July 1, 1962, to June 30, 1963*—Continued

Location No. (fig. 19)	Discharge (cfs)	Date of collection	Parts per million								Specific conductance (micromhos at 25° C.)	pH
			Silica (SiO_2)	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Alkyl benzene sulfonate (ABS)	Hardness as $CaCO_3$ Calcium Magnesium		
65	*2	9-25-62			90		8.0		0.03	91	220	7.5
57		9-25-62			110		7.0		.03	110	252	7.5
	17.5	10-29-62			94		6.5		.04	96	225	7.4
53		9-26-62			39	10	1.5		.05	40	99	7.2
53a	*2	9-26-62			18		2.5		.09	13	38	6.9
52	*2.2	9-26-62			90		6.0		.06	106	253	7.6
49	99	10-29-62	9.2		26	62	3.5		.02	91	221	7.0
	417	2-21-63			22	34				59	189	6.4
	213	3-1-63			32	39				63	170	6.9
	2,880	3-8-63			12	16				32	99	5.9
	1,820	3-14-63			13	20				33	110	6.4
43	*7.4	9-25-62			228	32			.09	282	682	7.4
42	*14	9-25-62			188		104		1.2	230	1,140	6.9
41	.8	9-26-62			134	334	8.5		.04	416	866	7.2
39		9-25-62			175		13		.08	308	776	7.2
38	*2	9-26-62	15		220	24	10	3.1	.02	226	458	7.9
36	*.6	9-25-62			228		6.5		.03	226	446	7.5
34	*1.2	9-26-62	16		205	18	7.0	2.4	.04	202	411	7.7
32	3.2	9-26-62			229		7.0		.05	228	464	7.5
31		9-26-62			228		44		.70	252	770	7.0
30	*.2	9-26-62			58		4.0		.02	52	157	6.9
26	*40	9-26-62	9.0		234	63	23		.35	255	617	7.1
	39.1	10-24-62	8.5		238	59	15		.40	260	570	7.9
24	142	10-29-62			200		14		.32	224	516	7.5
22	*.4	9-27-62			138		5.5		.01	118	273	7.6
		3-7-63	4.2	[1]0.81	34	6.1	6.0	7.0		36	117	6.4
20	*2.5	9-27-62			16		1.5		.03	13	35	6.8
		3-7-63	8.7	.00	8	7.6	2.0	2.8		15	52	6.3
18	*3	9-27-62			40	4.2	2.0		.03	33	80	7.1

16	142	10-29-62	--	--	84	59	9.5	--	0.12	132	325	7.2
	545	2-21-63	--	--	62	37	--	--	--	97	277	6.9
	271	3- 1-63	--	--	70	39	--	--	--	103	269	7.0
	3,790	3- 8-63	--	--	36	19	--	--	--	54	149	6.5
	3,040	3-14-63	--	--	40	25	--	--	--	61	165	6.6
13	*35	9-26-62	--	--	215	37	16	--	.10	212	497	7.4
10	173	10-29-62	--	--	105	--	--	--	.11	144	343	7.5
	501	2-21-63	--	--	68	39	--	--	--	102	269	6.9
	335	3- 1-63	--	--	86	42	--	--	--	128	306	7.2
	3,720	3- 8-63	--	--	32	18	--	--	--	51	140	6.2
	2,780	3-14-63	--	--	42	24	--	--	--	63	168	6.8
8	--	9-27-62	--	--	102	0.0	--	--	.04	92	217	7.6
7	*3	9-27-62	--	--	131	--	9.0	--	.04	116	278	7.4
1	175	10-29-62	--	--	96	51	9.0	--	.12	148	340	7.4
	629	2-21-63	--	--	74	38	--	--	--	106	278	6.9
	302	3- 1-63	--	--	88	41	--	--	--	120	301	7.3
	5,530	3- 8-63	--	--	32	18	--	--	--	52	141	6.2
	3,910	3-14-63	--	--	43	24	--	--	--	65	171	6.9

[1] In solution when analyzed.

TABLE 13.—*Locations of recovered flood marks along Swatara Creek for flood of August 1933*

Location No. (fig. 19)	Elevation (feet above mean sea level)	Description of mark
2	305(approx)	Mark on basement wall of residence of John C. Kugle, on right bank, first house downstream from covered bridge, 3.9 miles above mouth.
3	322.6	Mark on wall, 30 in. above concrete floor of well house of Ralph Logan, on left bank just upstream from Fiddler's Elbow covered bridge 7.2 miles above mouth.
9	331.0	Mark on outside wall of Hummelstown filtration plant on Duke St., 10.6 miles above mouth.
21	352.3	Red keel mark above doorway of shed at rear of Weaver residence (tan stucco house) on right bank of Swatara Creek at Sand Beach, 15.7 miles above mouth.
23	356.4	Mark on rear porch of residence of Morris Leese, on right bank upstream from Linesville bridge and 19.6 miles above mouth.
47	356.7	Chiseled mark in door frame of barn on farm of Alvin Stauffer, on right bank of Swatara Creek and 21.8 miles above mouth.
49	374.21	Recorded mark at gaging station at bridge at Harper Tavern, 28.4 miles above mouth.
55	378.2	Mark on frame of garage door at residence of Joel Yorty, on right bank of bridge, 30.3 miles above mouth.
56	390.2	Point on floor of Arnold residence, on left bank downstream from bridge and 33.3 miles above mouth.
57	398.7	Notch cut in left upstream corner of residence of Wayne Steetz, on left bank just upstream from abandoned powerplant and 35.7 miles above mouth.
67	408.5	Mark on wall in pump room of water treatment plant at Jonestown.
68	423.3	Mark on door jamb, 5 ft above floor of lower level of basin on Forge Creek, behind residence of Joseph Mease in Lickdale, 41.5 miles above mouth.
69	431.2	Mark on inside wall of garage behind residence on H. L. Coleman's farm, about 1 mile upstream from Lickdale and 43.2 miles above mouth.
71	452.7	Notch cut in east side of 18-in. pine tree about 50 ft west of residence of Cora Diechert, on Route 72, 0.1 mile north of intersection with Route 443.
77	478.1	Mark on wall of loft of small barn behind residence of Richard Rudegeair, on left bank at old canal lock 0.1 mile below Schuylkill-Lebanon County line and 50.6 miles above mouth.
78	484.7	Mark on porch foundation and in basement of Schneck residence, on right bank on downstream side of bridge of Suedberg and 52.4 miles above mouth.
85	503.2	Mark in basement of Pine Grove Roller Rink, on right bank south of Pine Grove and 55.6 miles above mouth.
89	515.1	Old line on walls of basement of Pine Grove Auto Service on right bank at East Pottsville St. in Pine Grove.

TABLE 14.—*Chemical analyses of samples from wells in Swatara Creek basin, July 1, 1962, to June 30, 1963*

Location No. (fig. 19)	Aquifer	Date of collection	Parts per million: Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Temperature (°F)
103	Mauch Chunk (Mississippian)	12-26-62	17	0.24	16	3.4	2.6	0.5	72	2.5	1.0	0.1	0.3	80	54	0	120	7.7	------
104	Marine beds (Upper Devonian)	1-7-63	27	1.3	14	7.8	8.2	1.0	100	2.9	.8	.2	.4	110	67	0	167	7.2	59
105	Marine beds (Upper Devonian)	1-7-63	13	.06	4.8	2.4	5.3	.8	14	.4	5.0	.0	18	64	22	11	85	6.2	58
106	Catskill (Devonian and Mississippian)	1-7-63	18	.78	11	6.8	4.4	1.0	74	3.4	1.7	.1	.3	85	56	0	134	7.0	56
107	Hamilton (Devonian)	1-8-63	9.0	.12	2.4	.5	3.1	.8	14	.0	.8	.1	3.4	31	8	0	32	6.2	52
108	Catskill (Devonian and Mississippian)	1-8-63	11	.12	7.2	3.9	4.4	2.0	8	14	5.9	.0	19	80	34	28	116	6.0	47
109	Bloomsburg and McKenzie (Silurian)	1-8-63	9.9	.66	8.0	3.6	4.0	1.5	26	4.8	4.0	.0	15	70	35	14	100	6.2	53
110	Catskill (Devonian and Mississippian)	1-8-63	8.8	.17	14	8.0	3.1	2.0	8	20	9.0	.0	45	120	68	62	183	6.1	50
111	Martinsburg (Ordovician)	1-9-63	21	.62	38	9.2	6.8	.8	144	26	1.9	.1	.3	178	133	15	297	7.6	54
112	Martinsburg (Ordovician)	1-9-63	14	.04	38	5.8	5.2	.8	124	11	6.1	.1	8.6	150	119	18	265	7.6	54
113	Martinsburg (Ordovician)	1-9-63	13	.54	13	6.3	9.0	.5	56	12	6.6	.1	11	100	59	13	165	6.8	54
114	Gettysburg (Triassic)	1-9-63	40	.14	42	1.7	6.7	1.5	150	.0	2.6	.0	3.2	173	112	0	259	7.0	48
115	Gettysburg (Triassic)	1-9-63	24	.35	4.0	1.7	4.2	3.0	22	.4	1.8	.0	11	61	17	0	66	6.1	40
116	Martinsburg (Ordovician)	1-10-63	21	.23	26	8.5	6.4	1.2	114	14	1.7	.1	.2	138	100	7	232	7.7	56
117	-------------------	1-11-63	9.2	2.4	26	6.6	3.6	1.0	101	6.7	8.6	.1	.8	111	92	9	212	6.8	51
118	-------------------	1-11-63	7.4	7.4	1.6	1.7	3.1	.8	9	3.2	1.8	.1	5.3	30	11	4	43	5.7	53
119	-------------------	1-11-63	------	------	38	18	------	------	150	38	------	------	------	288	166	------	361	7.3	51
120	-------------------	1-18-63	8.5	8.2	18	9.2	3.6	.0	93	10	2.4	.1	.2	99	83	7	186	6.5	60
121	-------------------	1-23-63	6.0	.31	5.2	2.7	2.0	1.2	6	14	2.4	.1	6.9	51	24	19	112	5.7	56

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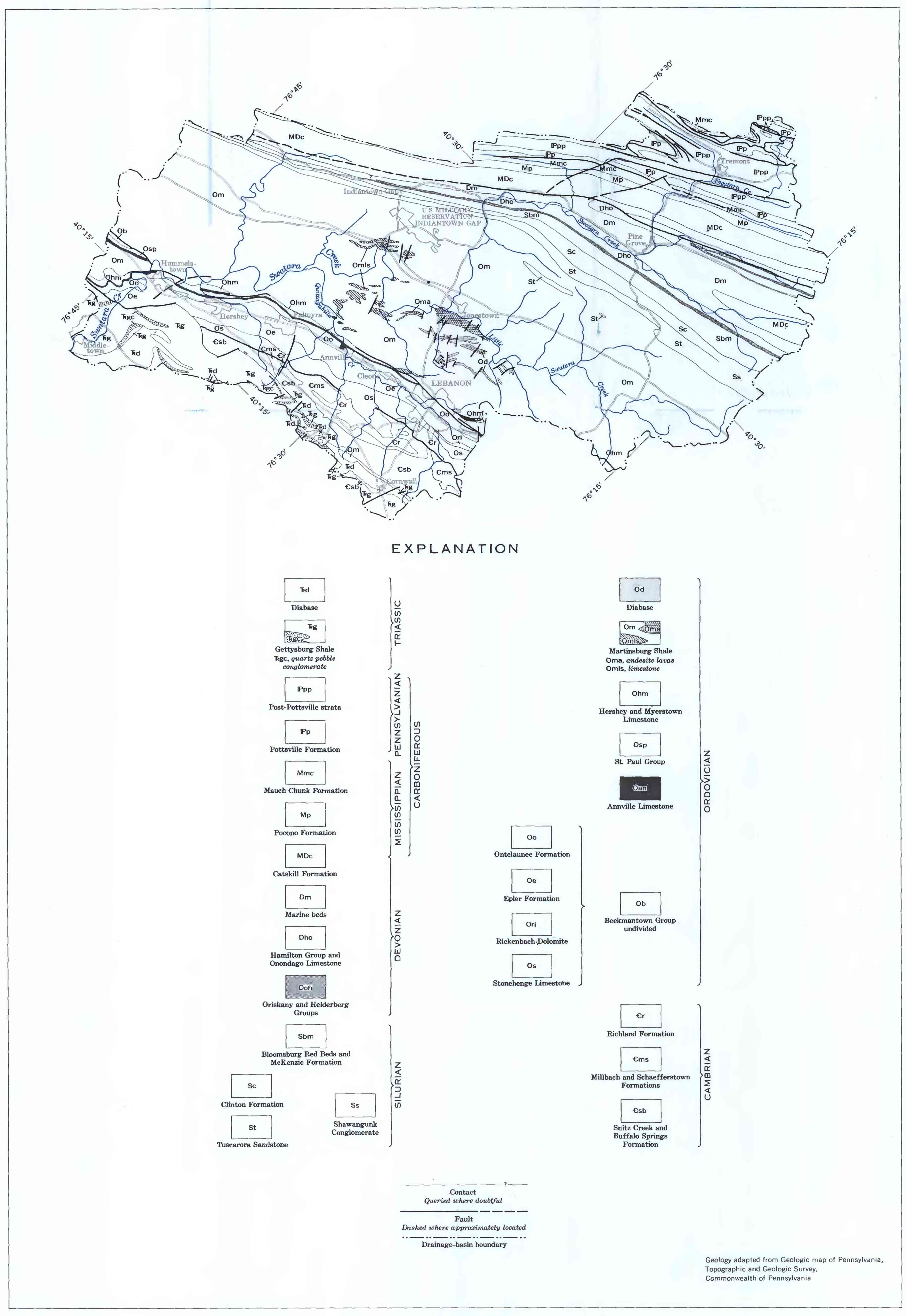
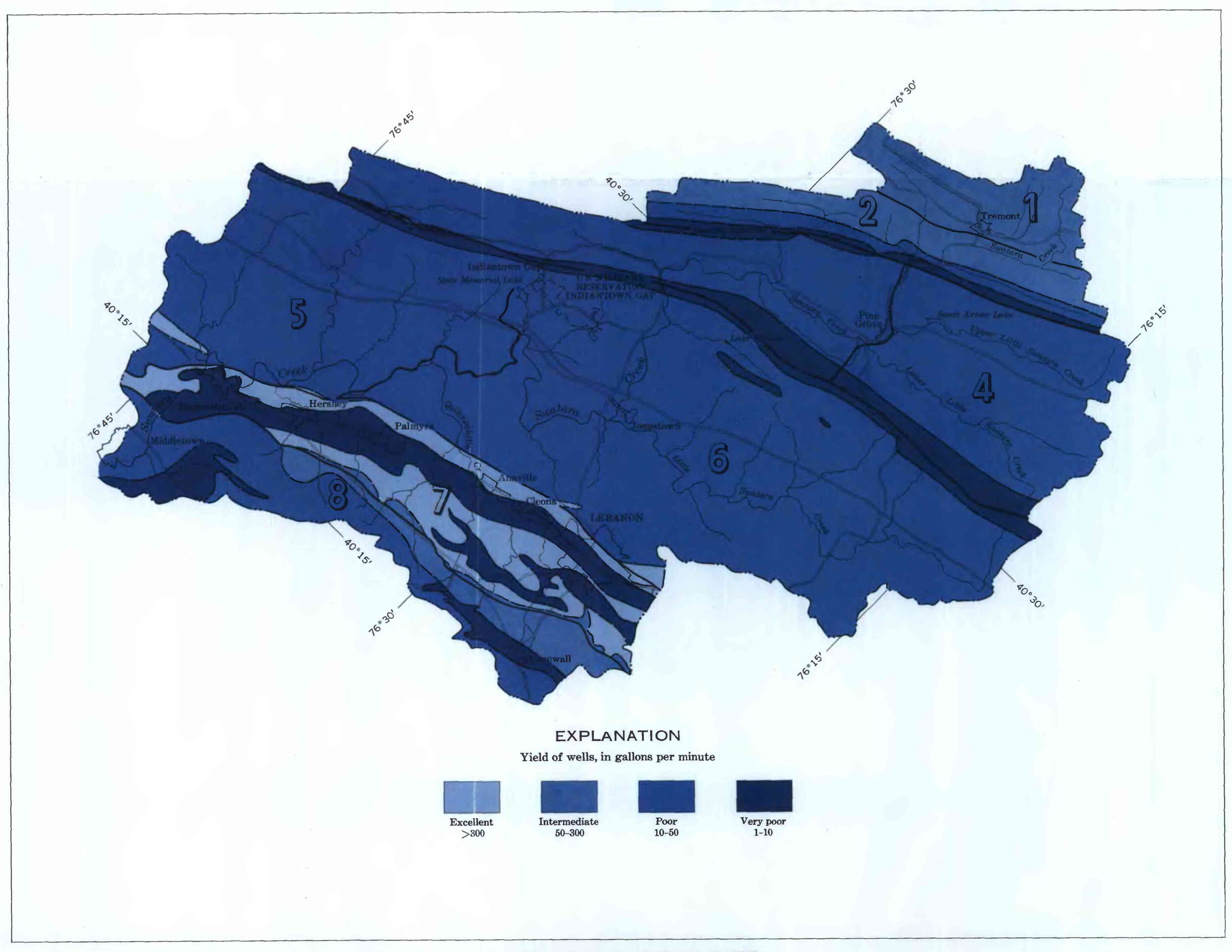
GEOLOGY

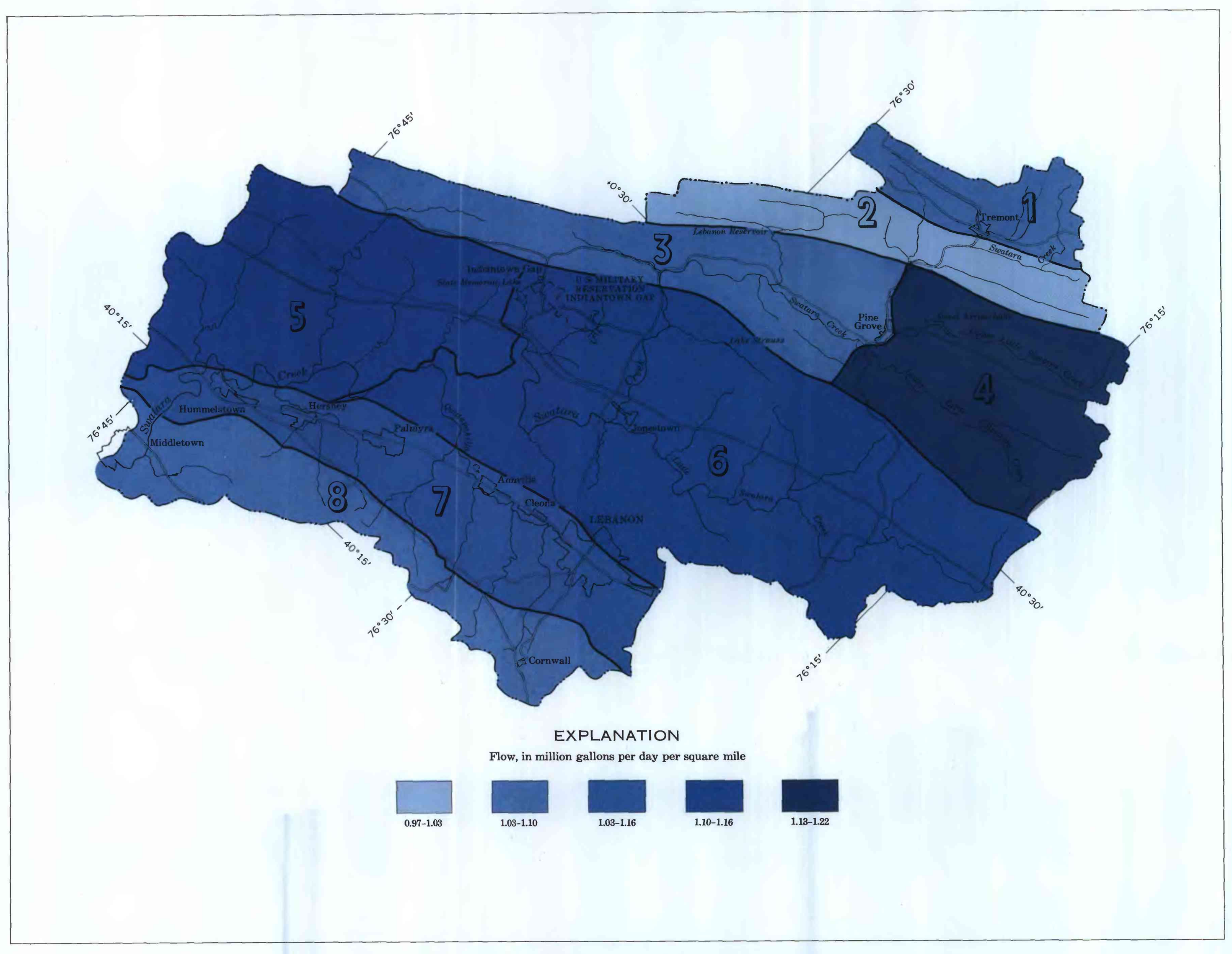


A. GEOLOGIC MAP

WATER AVAILABILITY

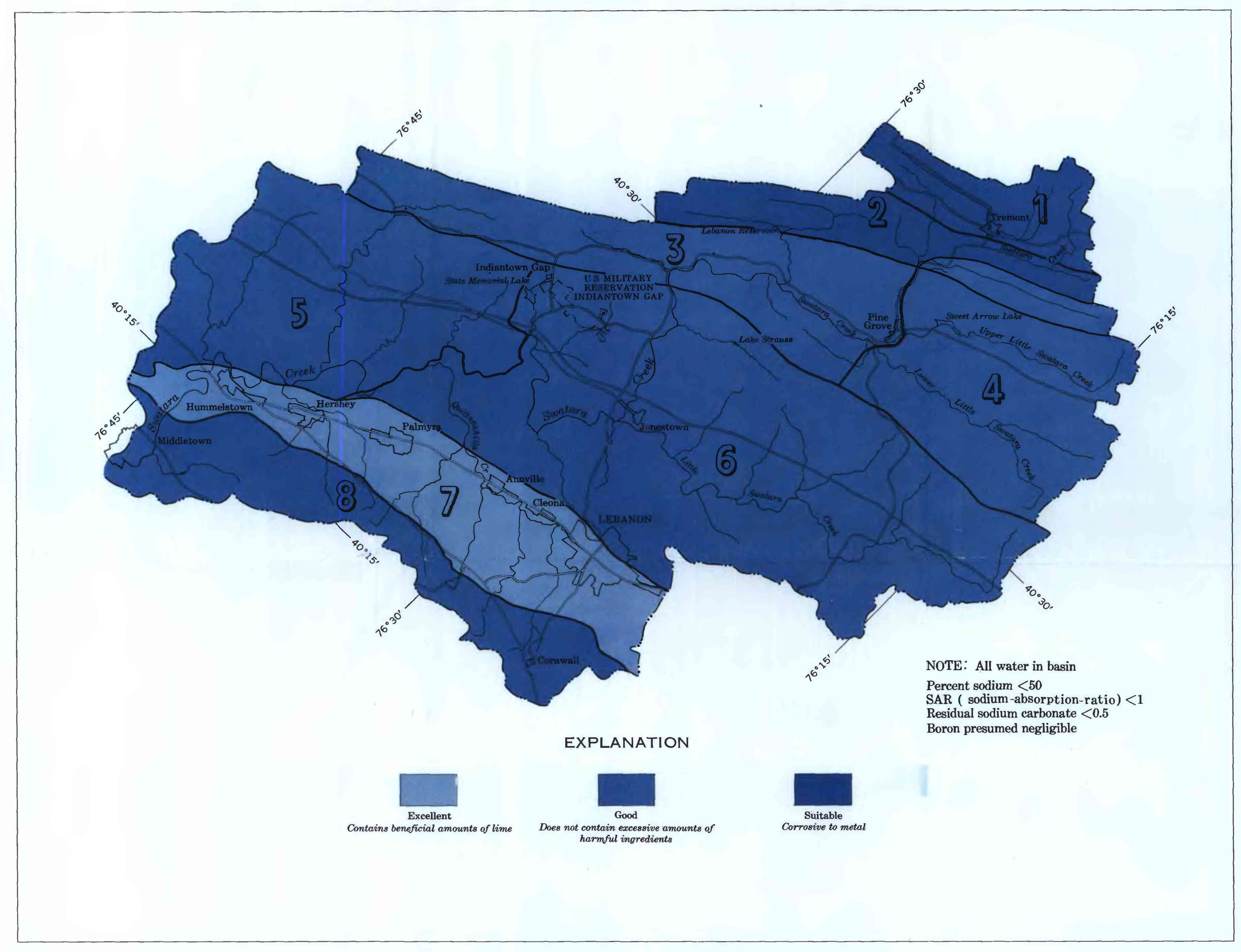


B. AVAILABILITY OF GROUND WATER

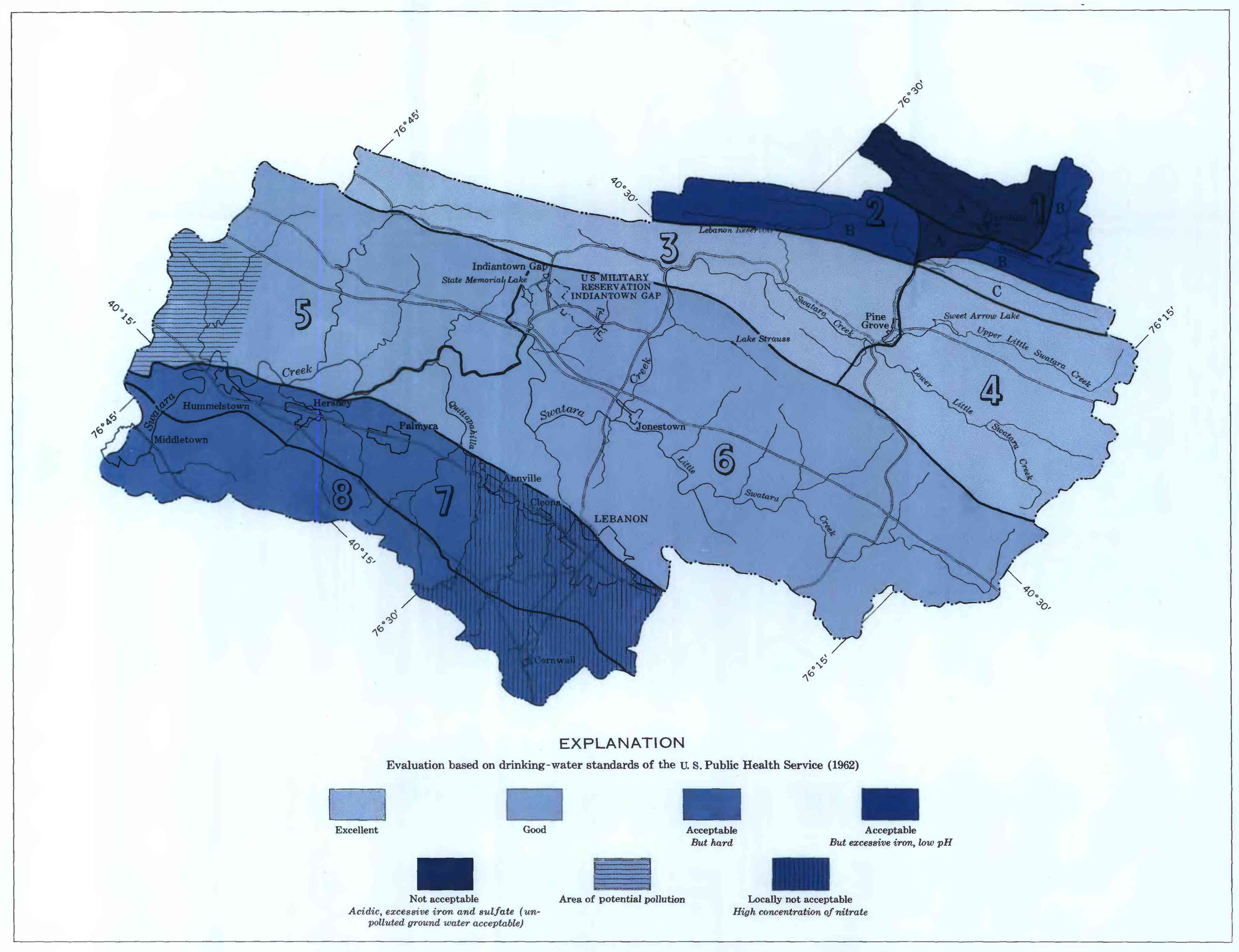


C. ZONAL VARIABILITY OF AVERAGE ANNUAL STREAMFLOW

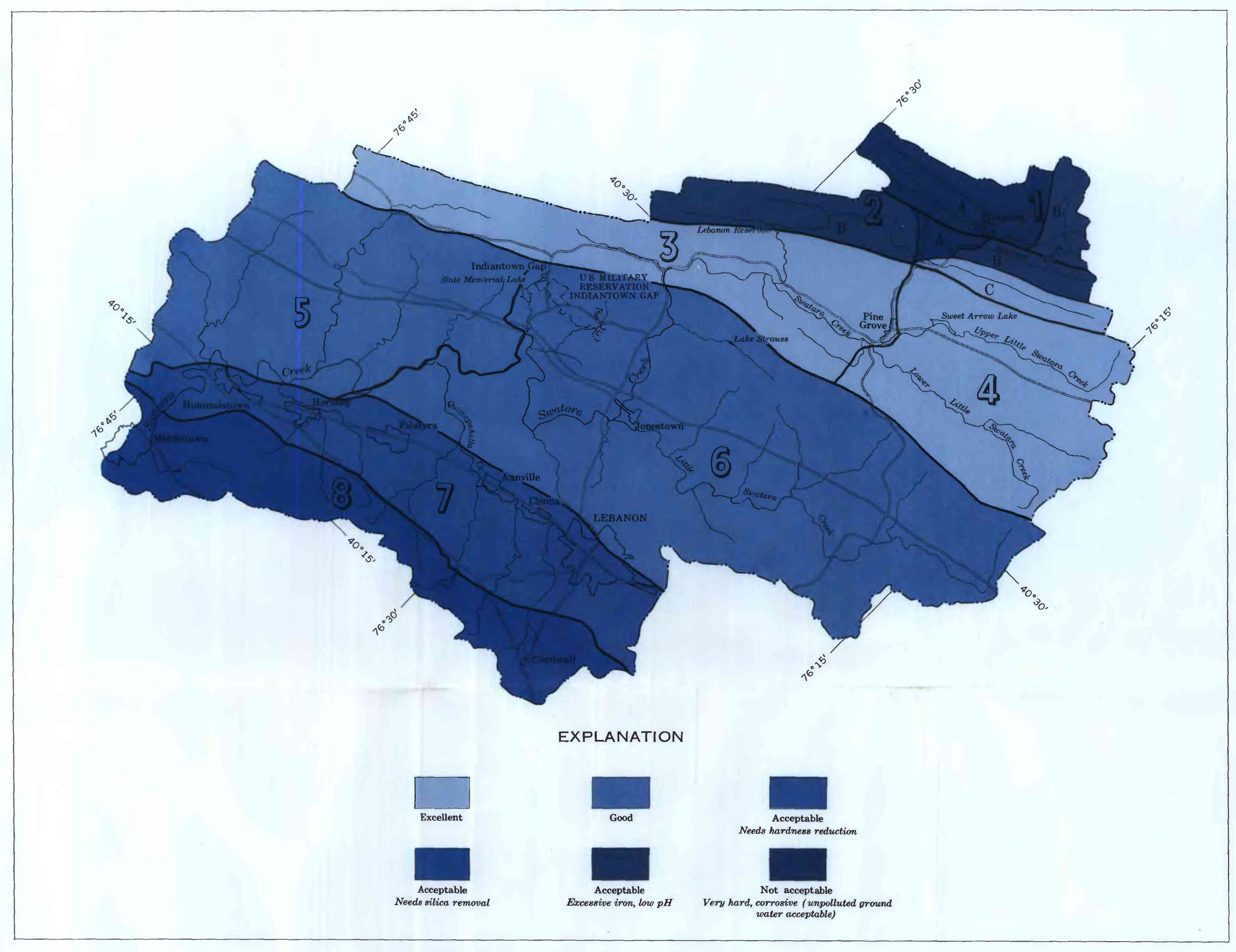
SUITABILITY OF WATER



D. SUITABILITY OF WATER FOR IRRIGATION



E. SUITABILITY OF WATER FOR PUBLIC SUPPLIES ON BASIS OF CHEMICAL CHARACTERISTICS



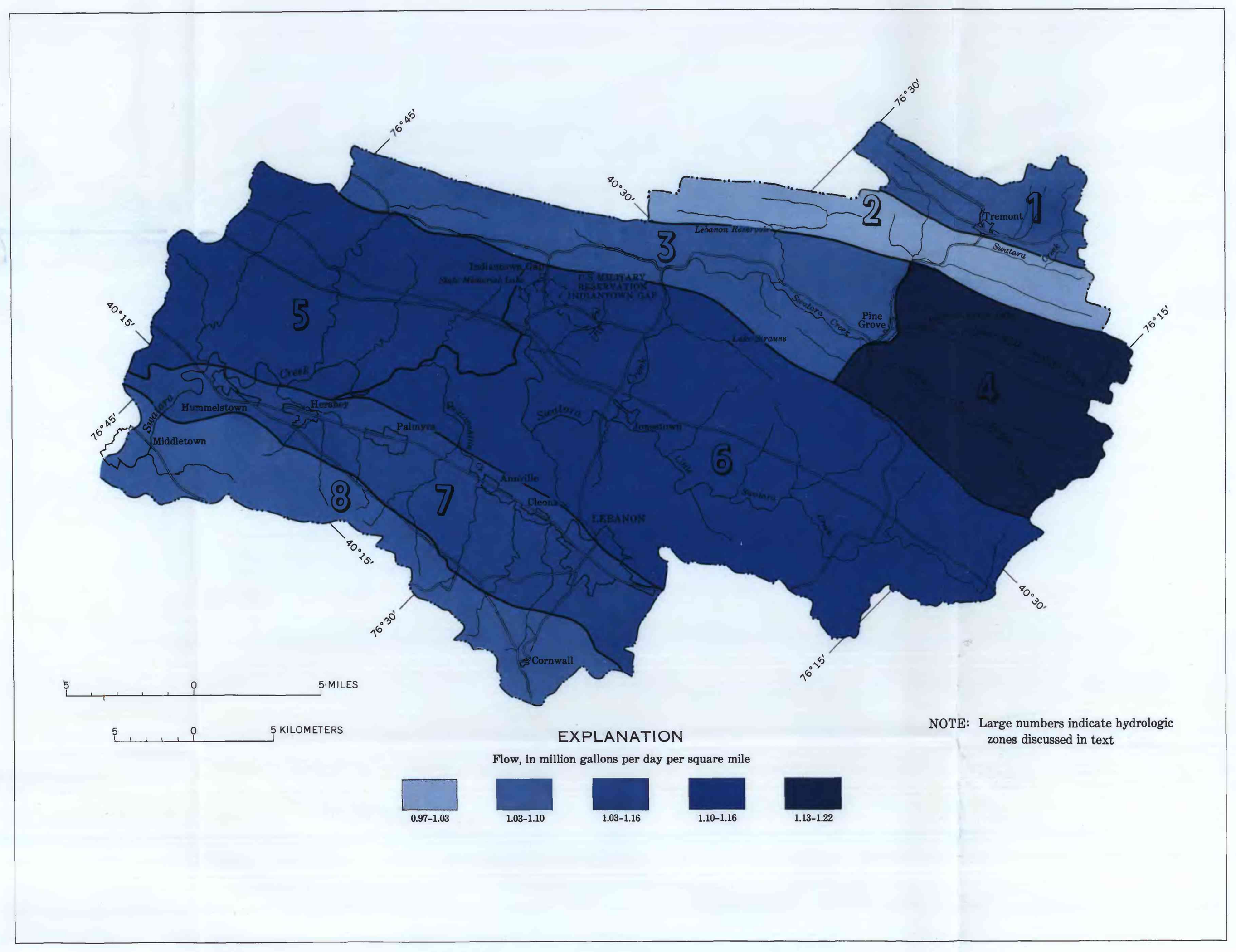
F. SUITABILITY OF WATER FOR INDUSTRIAL USE

5 0 5 10 15 MILES

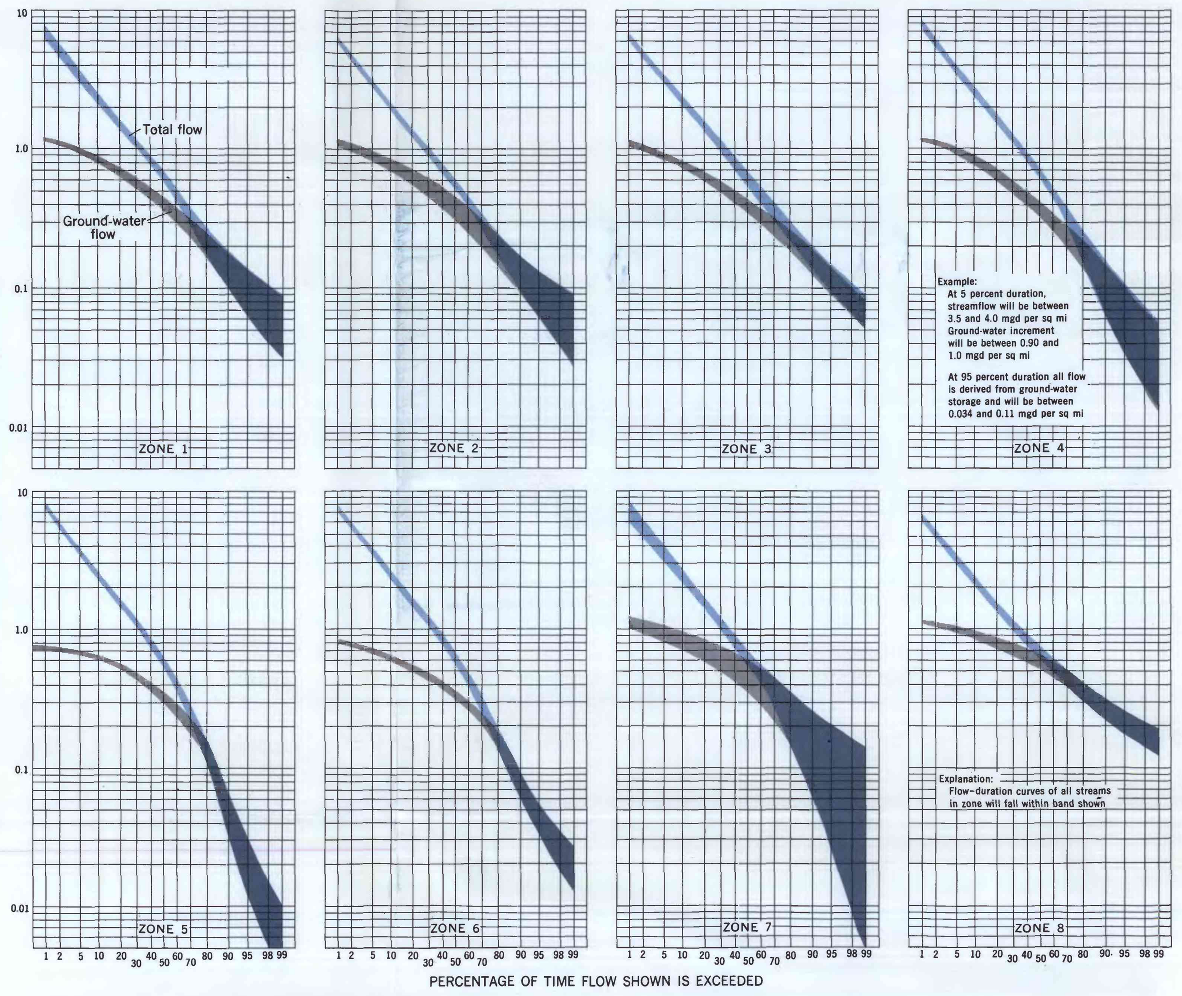
5 0 5 10 15 KILOMETERS

NOTE: Large numbers indicate hydrologic zones discussed in text
Letters indicate subdivisions of hydrologic zones

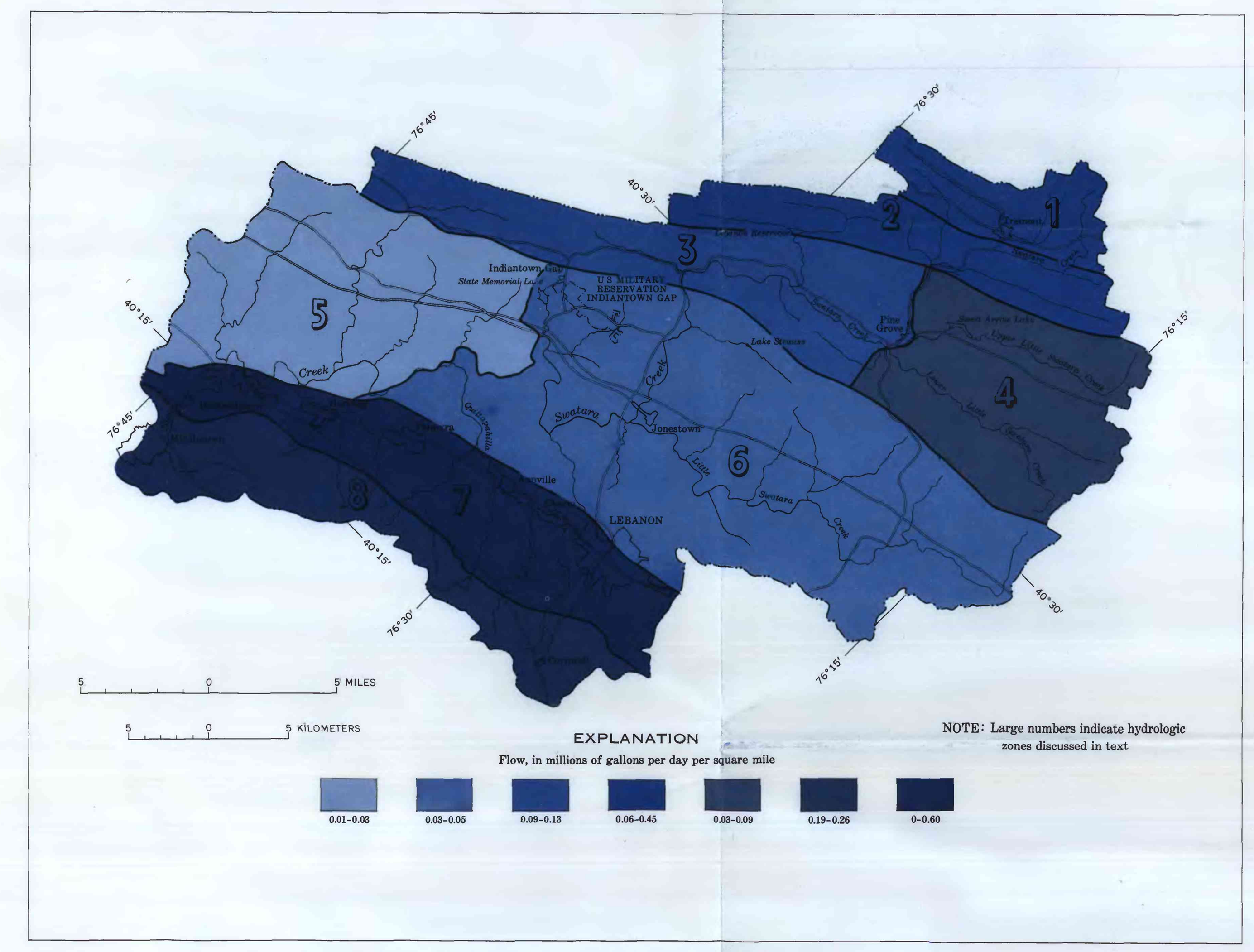
MAPS SHOWING GEOLOGY, WATER AVAILABILITY, AND SUITABILITY OF WATER IN THE SWATARA CREEK BASIN, SOUTHEASTERN PENNSYLVANIA



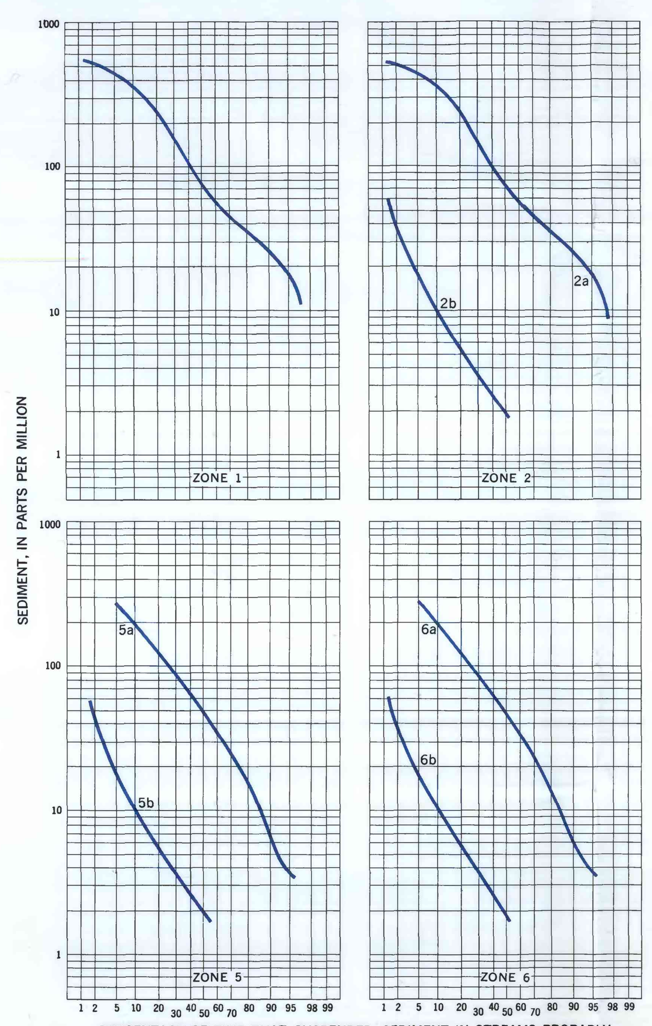
A. ZONAL VARIABILITY OF AVERAGE ANNUAL STREAMFLOW



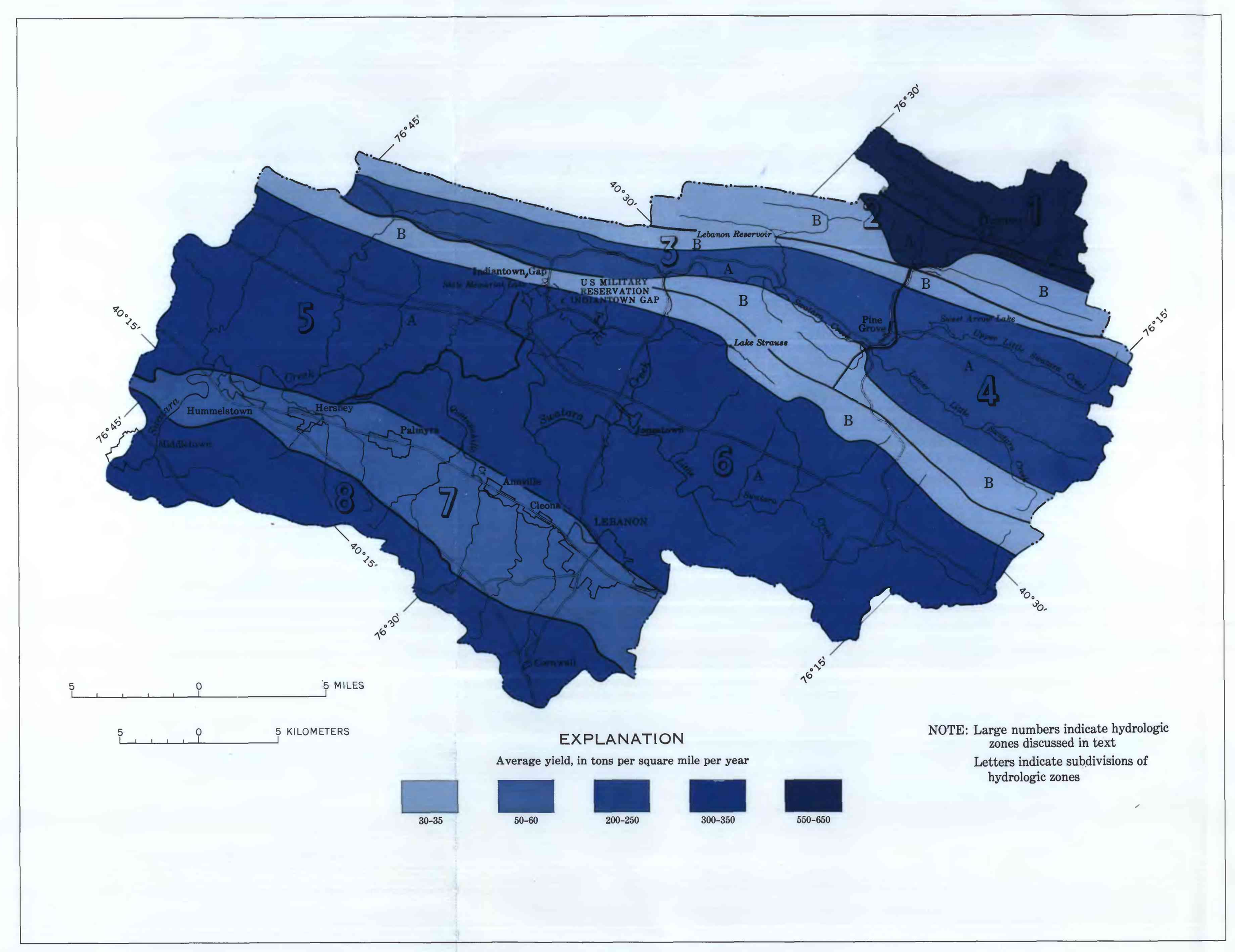
B. FLOW-DURATION CURVES OF STREAMS IN HYDROLOGIC ZONES OF SWATARA CREEK BASIN



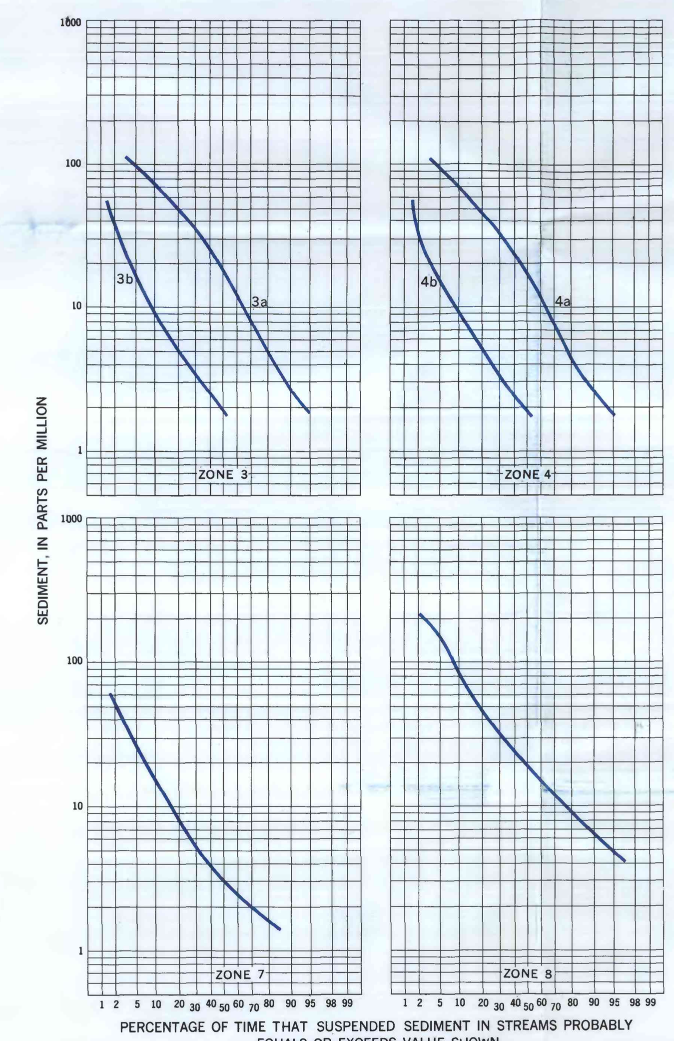
C. ZONAL VARIABILITY OF AVERAGE ANNUAL LOW FLOWS OF STREAMS



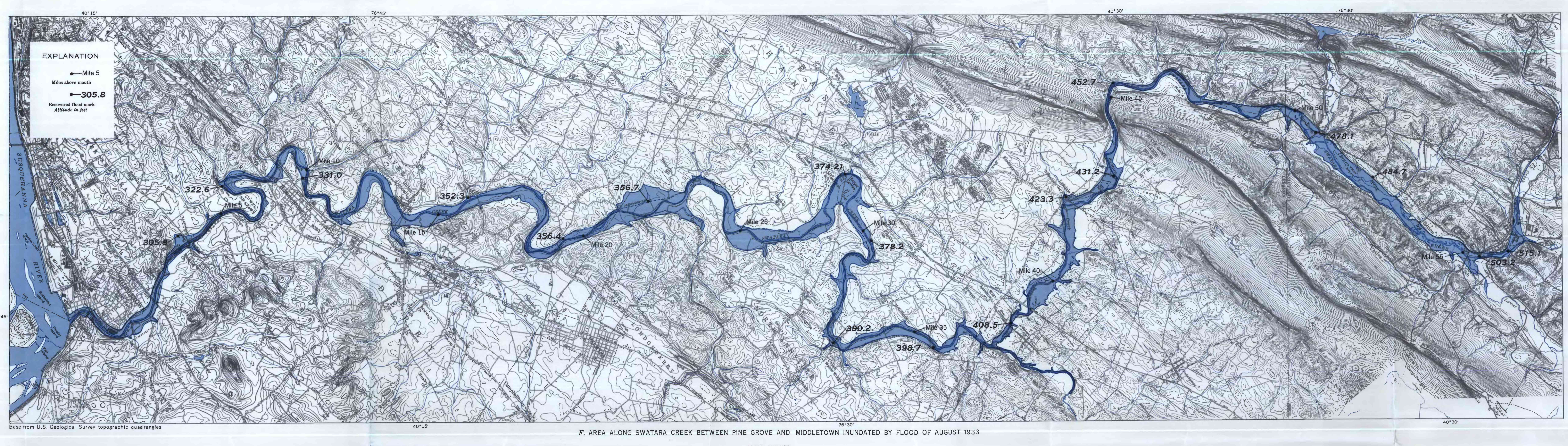
D. ZONAL VARIABILITY OF DURATION OF SEDIMENT CONCENTRATION IN STREAMS



E. ZONAL VARIABILITY OF SEDIMENT YIELD



D. ZONAL VARIABILITY OF DURATION OF SEDIMENT CONCENTRATION IN STREAMS

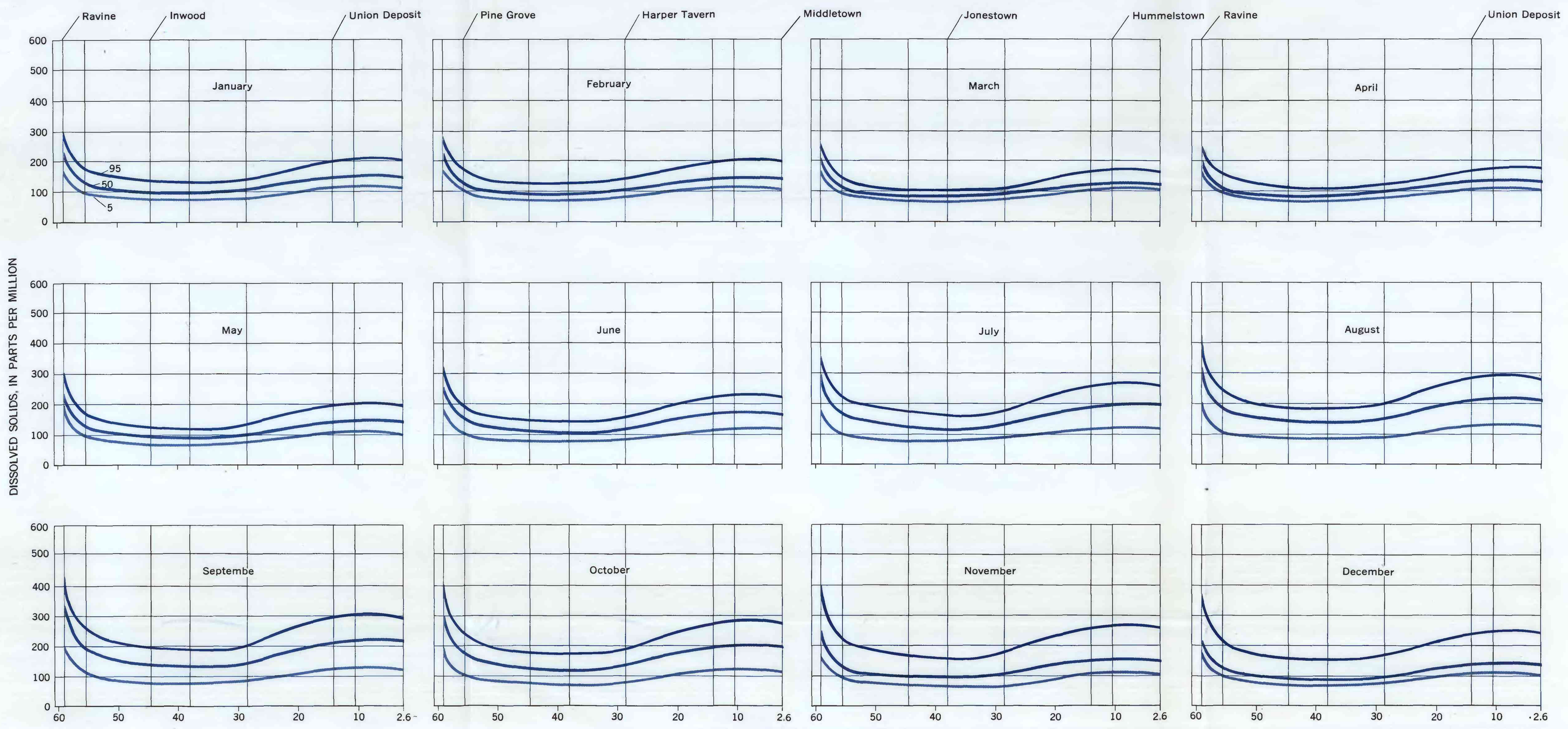


F. AREA ALONG SWATARA CREEK BETWEEN PINE GROVE AND MIDDLETOWN INUNDATED BY FLOOD OF AUGUST 1933

SCALE 1:62 500

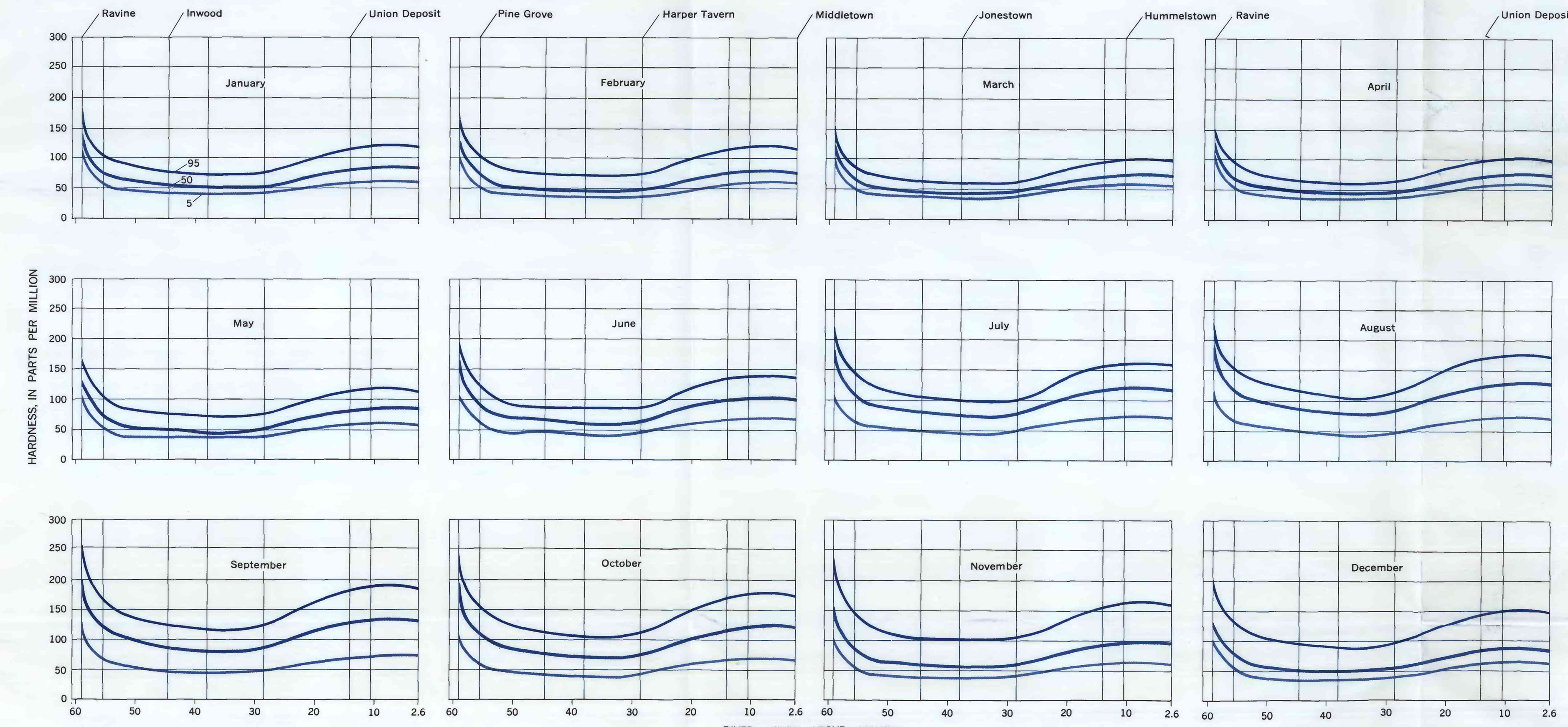
INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1967—W44167

MAPS AND GRAPHS SHOWING PHYSICAL CHARACTERISTICS OF STREAMFLOW IN THE SWATARA CREEK BASIN, SOUTHEASTERN PENNSYLVANIA



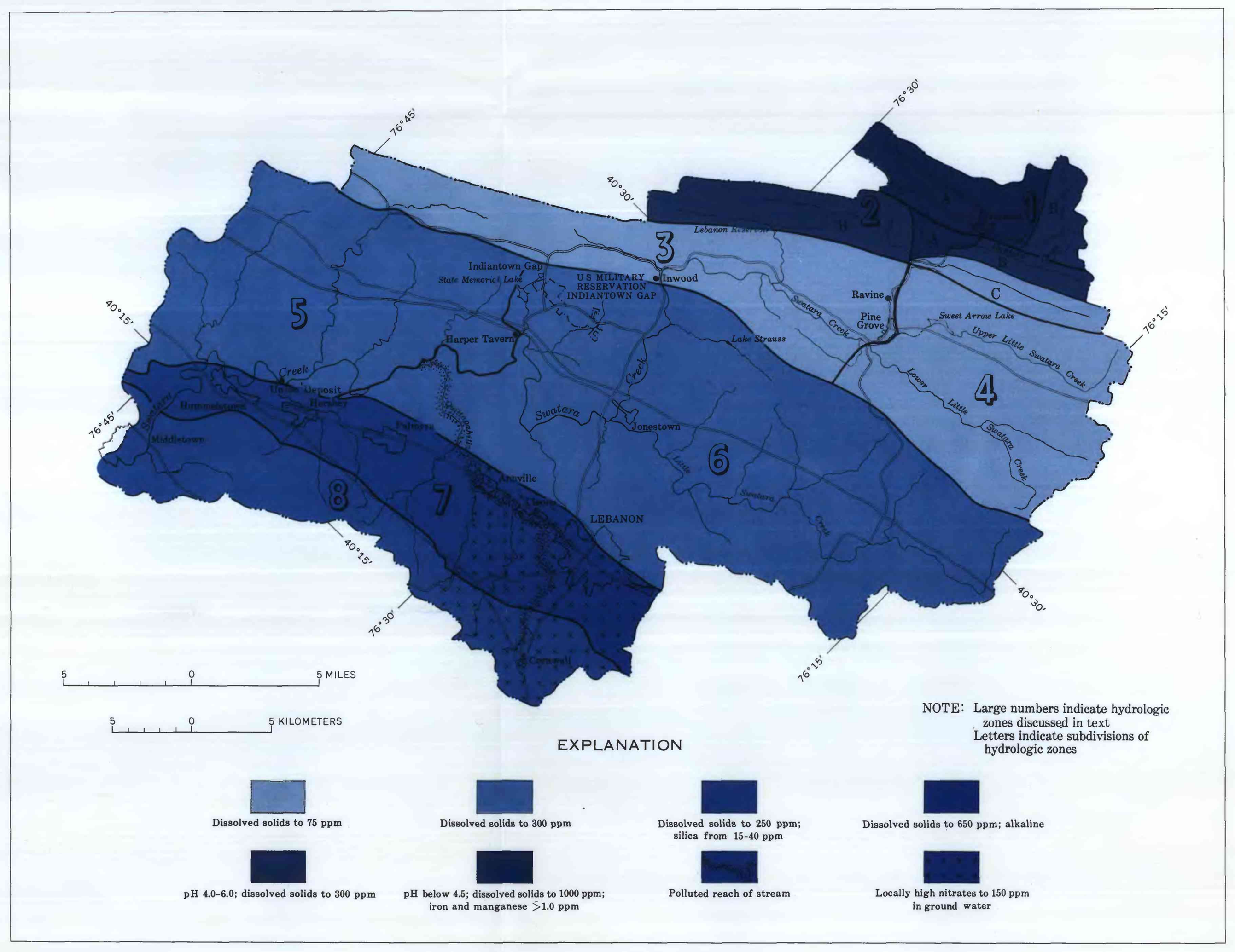
Note: Figures shown are percentage of time (5,50,95) that dissolved solids probably is equal to or less than value shown at any point.

A. MONTHLY CALENDAR OF DISSOLVED SOLIDS IN SWATARA CREEK—RAVINE TO MIDDLETOWN

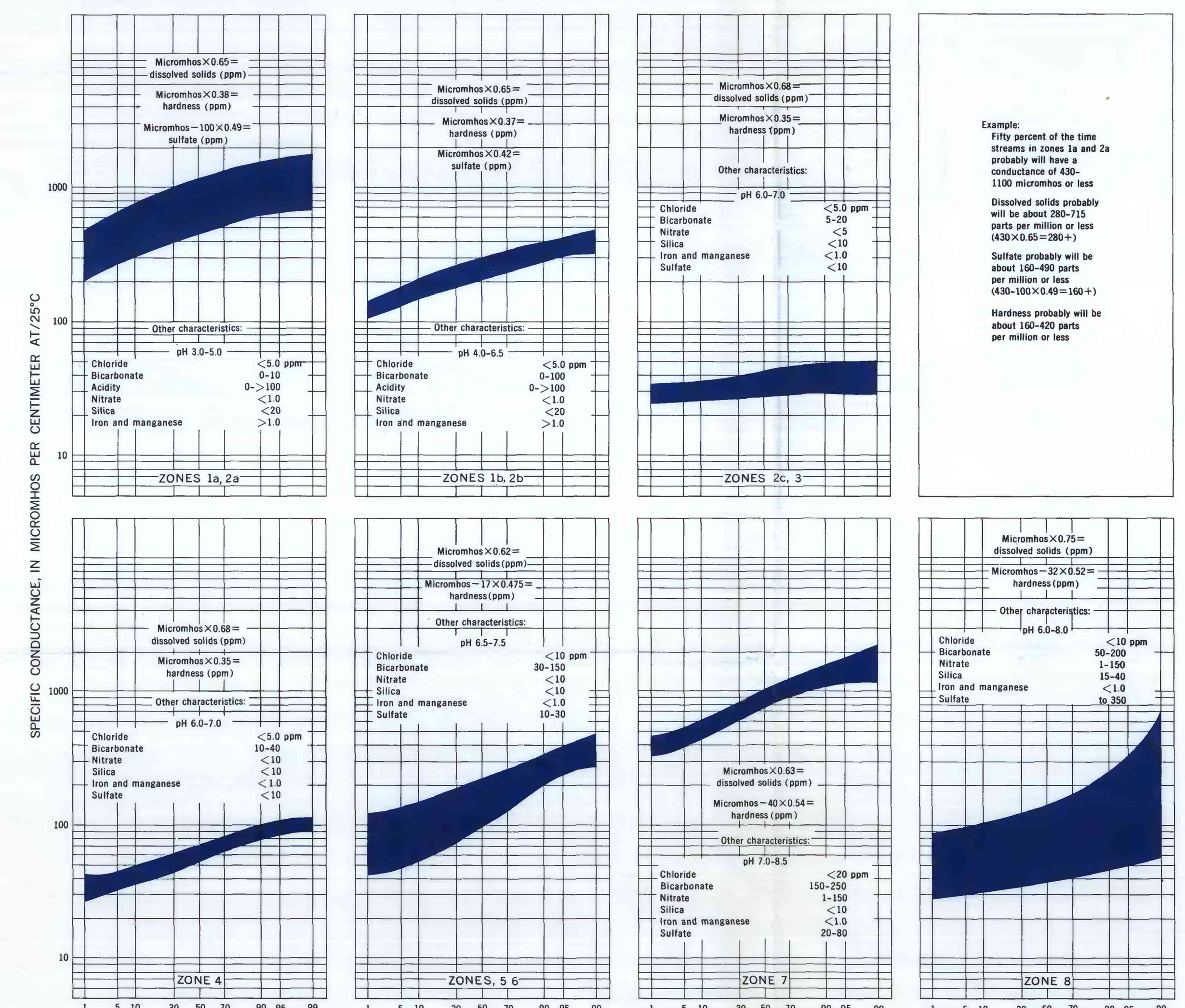


Note: Figures shown are percentage of time (5,50,95) that hardness probably is equal to or less than value shown at any point.

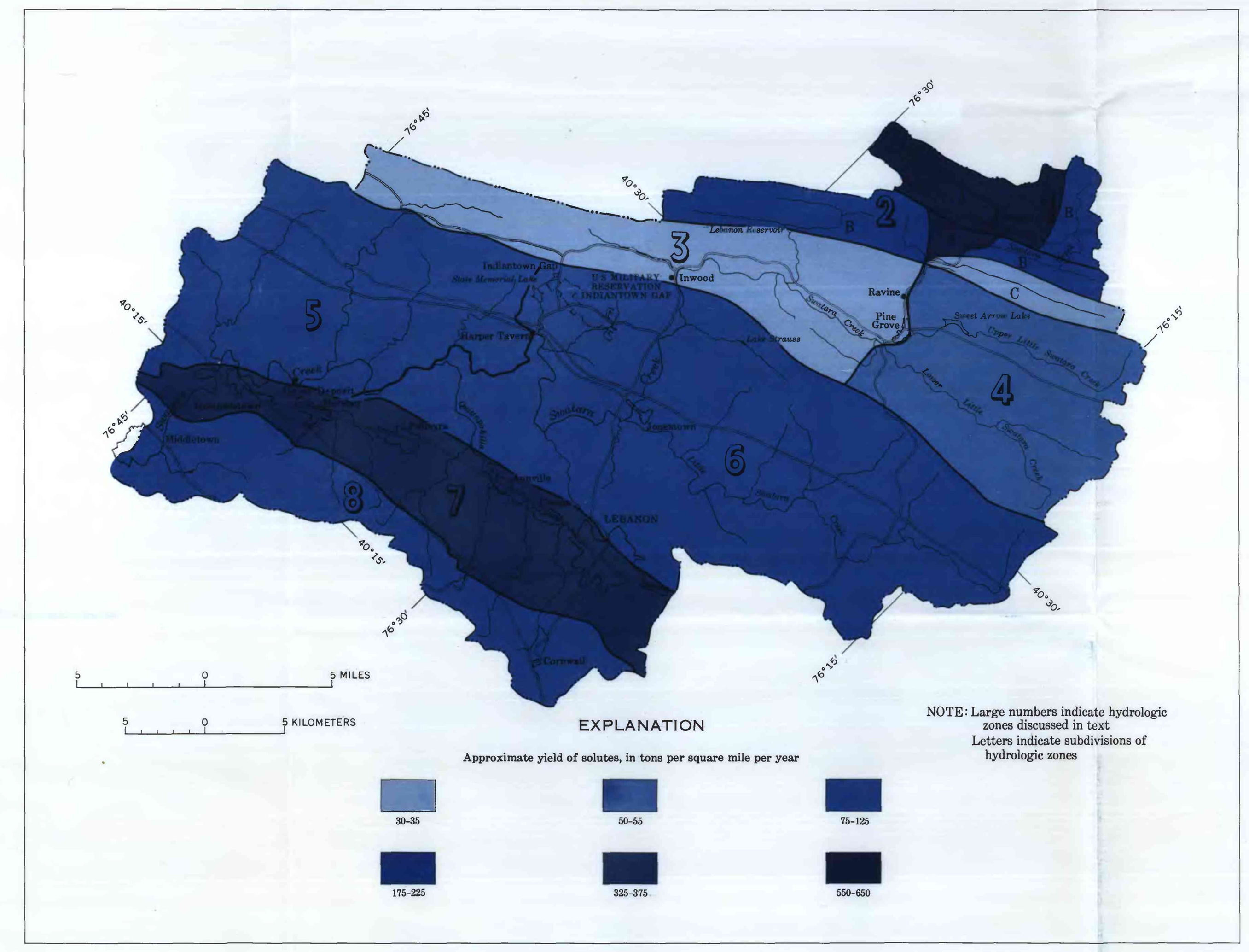
B. MONTHLY CALENDAR OF HARDNESS IN SWATARA CREEK—RAVINE TO MIDDLETOWN



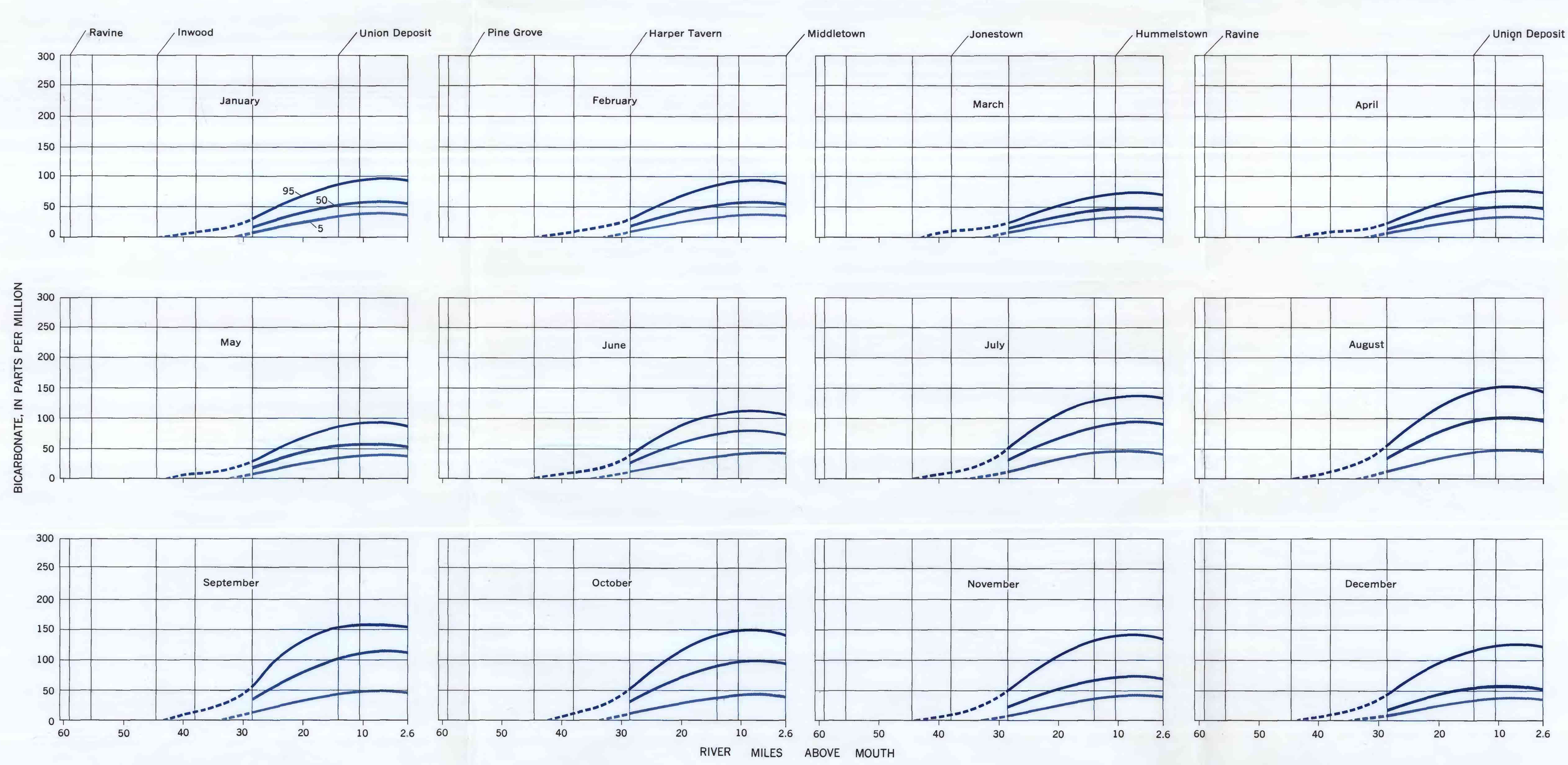
C. CHEMICAL CHARACTERISTICS OF STREAMS AT LOW FLOW



D. ZONAL VARIABILITY OF DURATION OF CHEMICAL CHARACTERISTICS OF STREAMFLOW

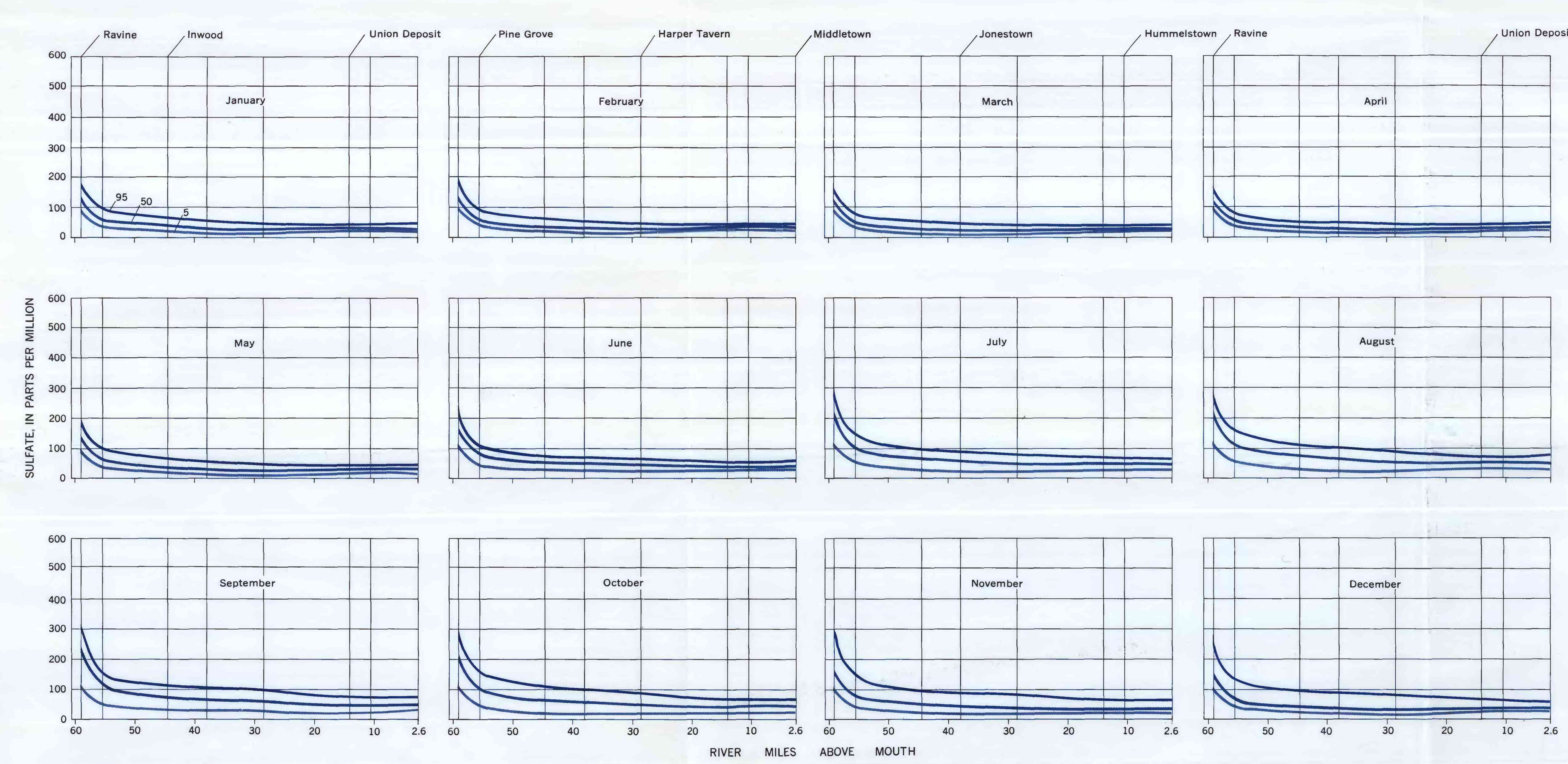


E. ZONAL VARIABILITY OF SOLUTE YIELD



Note: Figures shown are percentage of time (5,50,95) that bicarbonate probably is equal to or less than value shown.

F. MONTHLY CALENDAR OF BICARBONATE IN SWATARA CREEK—RAVINE TO MIDDLETOWN



Note: Figures shown are percentage of time (5,50,95) that sulfate probably is equal to or less than value shown.

G. MONTHLY CALENDAR OF SULFATE IN SWATARA CREEK—RAVINE TO MIDDLETOWN

MAPS AND GRAPHS SHOWING CHEMICAL CHARACTERISTICS OF STREAMFLOW IN THE SWATARA CREEK BASIN, SOUTHEASTERN PENNSYLVANIA