CHAPTER THREE

GROUNDWATER SYSTEMS IN SUSSEX COUNTY

This chapter will present the "fons et oigo"[8] of the groundwater solution, its groundwater resources, its indigenous problems, and recommended management solutions. To do this the text will trace over the relevant geologic history in order that the reader may gain a basic understanding of why aquifers are where they are as well as the general physiographic complexion of the County. Following the description of the geology of the County, the discussion will turn to characteristic soils and finally to the groundwater yields associated with the various formations and soils.

Geology (Adapted from Carol S. Lucey, "The Geology of Sussex County in Brief", New Jersey Bureau of Geology and Joseph Miller).

Sussex County is a part of two physiographic provinces; the Appalachian Valley and Ridge Province and the Highlands. The Appalachian Valley and Ridge Province, which bisects the northwestern portion of the County, is underlain by Paleozoic sedimentary rocks and encompasses Kittatinny Mountain and the associated valleys. The portion of the Kittatinny Mountain range which lies in New Jersey is approximately forty miles long and from one to five miles wide. The ridge is composed of Shawangunk quartzite and conglomerate, which are hard and resistant to weathering. The valleys are underlain by less resistant shales, dolomites, and limestones. Because the shales are prone to fracturing, they are vulnerable to erosion. The dolomites and limestones are slightly soluble in water and offer the least resistance to weathering.

The New Jersey Highlands are actually a portion of the Reading Prong of the New England Highlands Province. The Highlands are a series of ridges, several of which are in Sussex County, which are composed of very resistant, crystalline, Precambrian igneous and metamorphic rocks. The mountain crests average around one thousand feet above sea level in elevation. The ridges average about 25 miles long and one mile in width in the County. The Highlands comprise the southeastern portion of Sussex County.

The Sussex County landscape is a reflection of the composition of the geologic formations which lie under it. These formations are the products of the sequence of geologic events which have taken place over a period of over 600 million years.

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8. *Taken from the Latin; meaning source and origin*

The history of geologic events in Sussex County can be described briefly as consisting of periods of shallow sea submersion resulting in the deposition of limestone, shale, sandstone, and siltstone formations on existing Precambrian gneisses, schists, and quartzites. The sedimentary deposits underwent stratified compaction, followed by uplift and extensive folding and faulting. This activity created the ridges and valleys and highlands consisting of intensively folded, faulted, and fractured rock. Differential erosion, resulting from the runoff produced by uplift, sculptured the landscape and flattened less resistant rock. The wide valleys which grace Sussex County scenery today give testimony to this geologic phenomenon. Finally, in relatively recent geologic time, Sussex County experienced three periods of glaciation. The most recent glacier, the Wisconsin, left the most visible evidence of its former existence in the form of lakes, stream beds, and extensive sand and gravel deposits. The combination of these geologic events has formed present-day topography in and around Sussex County.

A summary of the major geologic events in the area which is now Sussex County will follow in Table I and Figure 5.

The geographic representation of the geologic formations that were summarized in the table is displayed on Figures 6 and 7, which were taken from the Sussex County '208' Water Quality Management Plan.

Soils

Soils have an important relationship to groundwater because they, along with other factors, dictate the rate of recharge into subsurface water storage areas as well as ability to screen out possible contaminants through cation exchange capability and other phenomenon. Soils which possess similar characteristics can be grouped into associations. The Sussex County soil survey lists eleven associations and displays them on a map which will appear here as Figure 8. The eleven associations are described as follows:[9]

1. Chenango - Atherton-Braceville Association: Nearly level to very steep, deep, well-drained to very poorly drained loamy soils; on terraces

2. Hazen-Palmyra-Fredon Association: Nearly level to very steep, deep, well-drained and poorly drained loamy soils; on terraces, Kames, and outwash plains

3. Carlisle-Swamp Association: Nearly level, deep, very poorly drained organic soils and mineral soils; in depressions

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9. *The United States Department of Agriculture Soil Conservation Service, Soil Survey of Sussex County, New Jersey, August 1975, General Soils Map*

4. Livingston-Sloan-Wayland Association: Nearly level, deep, very poorly drained and poorly drained loamy soils; in depressions and flood plains

5. Washington-Wassaic-Rock outcrop Association: Gently sloping to steep, deep, and moderately deep, well drained loamy soils and limestone outcrops; on uplands

6. Swartswood-Nassau Association: Gently sloping to steep, deep and shallow, well drained and somewhat excessively drained loamy soils; on uplands

7. Nassau-Bath-Norwich Association: Gently sloping to very steep, shallow and deep, somewhat excessively drained and well drained loamy soils and nearly level, deep, very poorly drained very stony loamy soils; on uplands

8. Wassaic-Wooster-Rock outcrop Association: Gently sloping to very steep, moderately deep, and deep, well-drained loamy soils and limestone outcrops; on uplands

9. Rockaway-Hibernia-Whitman Association: Gently sloping to very steep, deep, well drained and somewhat poorly drained gravelly to very stony loamy soils and nearly level, deep, very poorly drained extremely stony loamy soils; on uplands

10. Rockaway-Rock outcrop-Whitman Association: Steep and very steep, deep, well-drained gravelly to very stony loamy soils; rock outcrops; and nearly level, deep, very poorly drained extremely stony loamy soils; on uplands

11. Rock outcrop-Oquaga-Swartswood Association: Rock outcrops and sloping to very steep, moderately deep and deep, well-drained very stony and extremely stony loamy soils; on uplands

As can be seen on the map, much of the upland soils, which cover most of the County, are capable of recharging the groundwater supplies. The soil associations most likely to be groundwater recharge areas when in combination with the right rock formation are numbers 6 and 7. These associations predominate in Stillwater, Hampton, Frankford, Lafayette, and Wantage.[10]

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10. *U.S. Department of Agriculture, Soil Survey for Sussex County, New Jersey, issued August, 1978, pg. 120.*

TABLE I

SUMMARY OF GEOLOGIC EVENTS IN SUSSEX COUNTY

Proterozoic Era	
Precambrian -	Metamorphosing of bedrock resulting from folding and compression followed by molten igneous intrusion causing further alteration.
Franklin Formation	A white crystalline limestone and marble containing some graphite and sandy layers. In Franklin and Ogdensburg large deposits of zinc ore and some iron ore are found.
Paleozoic Era	
Cambrian - Hardyston Quartzite Ordovician - Martinsburg Shale Kittatinny Limestone Silurian - Shawngunk deposition Devonian - Limestone Deposition	General subsidence causing encroachment of a shallow sea. Paleozic sediments were deposited during the Cambrian, Ordovician, Silurian and Devonian Periods.
Cenozoic Era	
Tertiary Period	Erosion of the Schooley peneplain resulting in even crests of Kittatinny Mountains and the Highlands.
Quaternary Period	
Pleistocene - Kansan Glacier Epoch Illinoian Glacier (Ice Age) Wisconsin Glacier	The Wisconsin ice sheet was the last of three during the Ice Age and produced unstratified and stratified drift which can be traced from Ogdensburg through Lafayette, Halsey and Balesville to Culvers Lake. Formation of glacial lakes, scouring of stream beds, deposition of till (including sand & gravel).

ERAS	PERIODS	EPOCHS	MILLIONS OF YEARS: DURATION	MILLIONS OF YEARS: BEFORE THE PRESENT	
CENOZOIC	Cenozoic	Pleistocene	1,000,000		glaciation
		Pliocene	12,000,000		
		Miocene	12,000,000		
		Oligocene	11,000,000		
		Eocene	22,000,000		
		Paleocene	5,000,000	63,000,000	
MESOZOIC	Cretaceous		72,000,000		Triassic erosion-sedimentation-igneous activity, faulting; Jurassic-early Cret. erosion
	Jurassic		46,000,000		
	Triassic		49,000,000	230,000,000	
PALEOZOIC	Permian		50,000,000		1) formation of Appalacian Geosyncline 2) sea submersion / sedimentation 3) sea withdrawal / erosion 4) resubmersion } volcanism 5) Appalacian Revolution (faulting, folding, uplift)
	Pennsylvanian		30,000,000		
	Mississippian		35,000,000		
	Devonian		60,000,000		
	Silurian		20,000,000		
	Ordovician		75,000,000		
	Cambrian		100,000,000	600,000,000	

Oldest rocks dated 3,000,000,000 years

Origin of earth 4-5,000,000,000 years

Precambrian time
1) intruded, faulted, folded and metamorphosed igneous, sedimentary & metamorphic rocks
2) extensive erosion

GEOLOGIC TIMETABLE

FIGURE 5

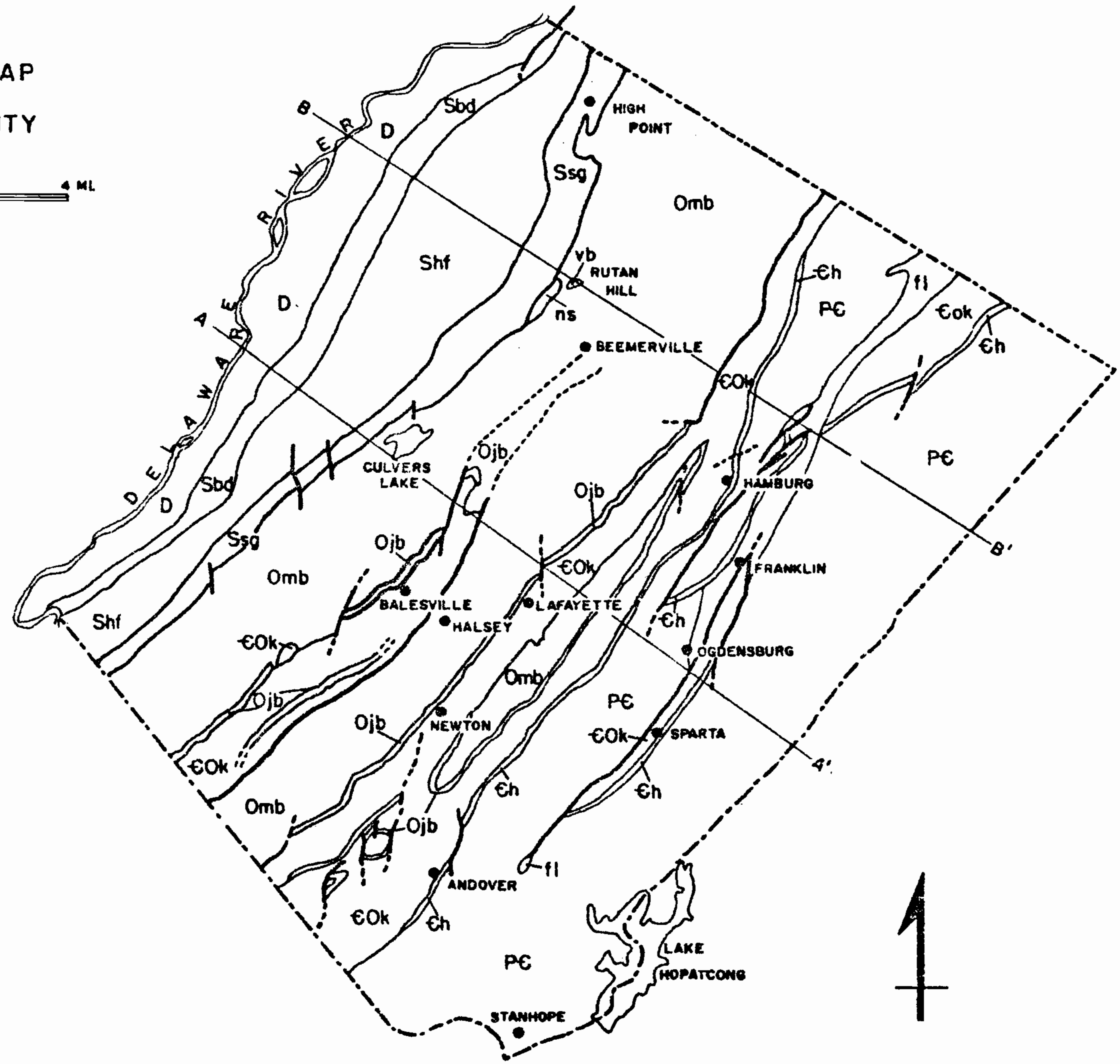
Source: Leet & Jodson, *Physical Geology*

FIGURE 6

GEOLOGIC MAP OF SUSSEX COUNTY

SCALE

4 3 2 1 0 4 MI.



LEGEND

D	Devonian limestone, shale & sandstone
Sbd	Silurian limestone & shale formations
Shf	High Falls Formation
Ssg	Shawangunk Conglomerate
Omb	Martinsburg Formation
Ojb	Jacksonburg Formation
€Ok	Kittatinny Formation
€h	Hardyston Quartzite
ns	Nepheline Syenite
vb	Volcanic Breccia
fl	Franklin Formation
P€	Precambrian (undifferentiated)

Fault——— Contact———

BOUNDARIES

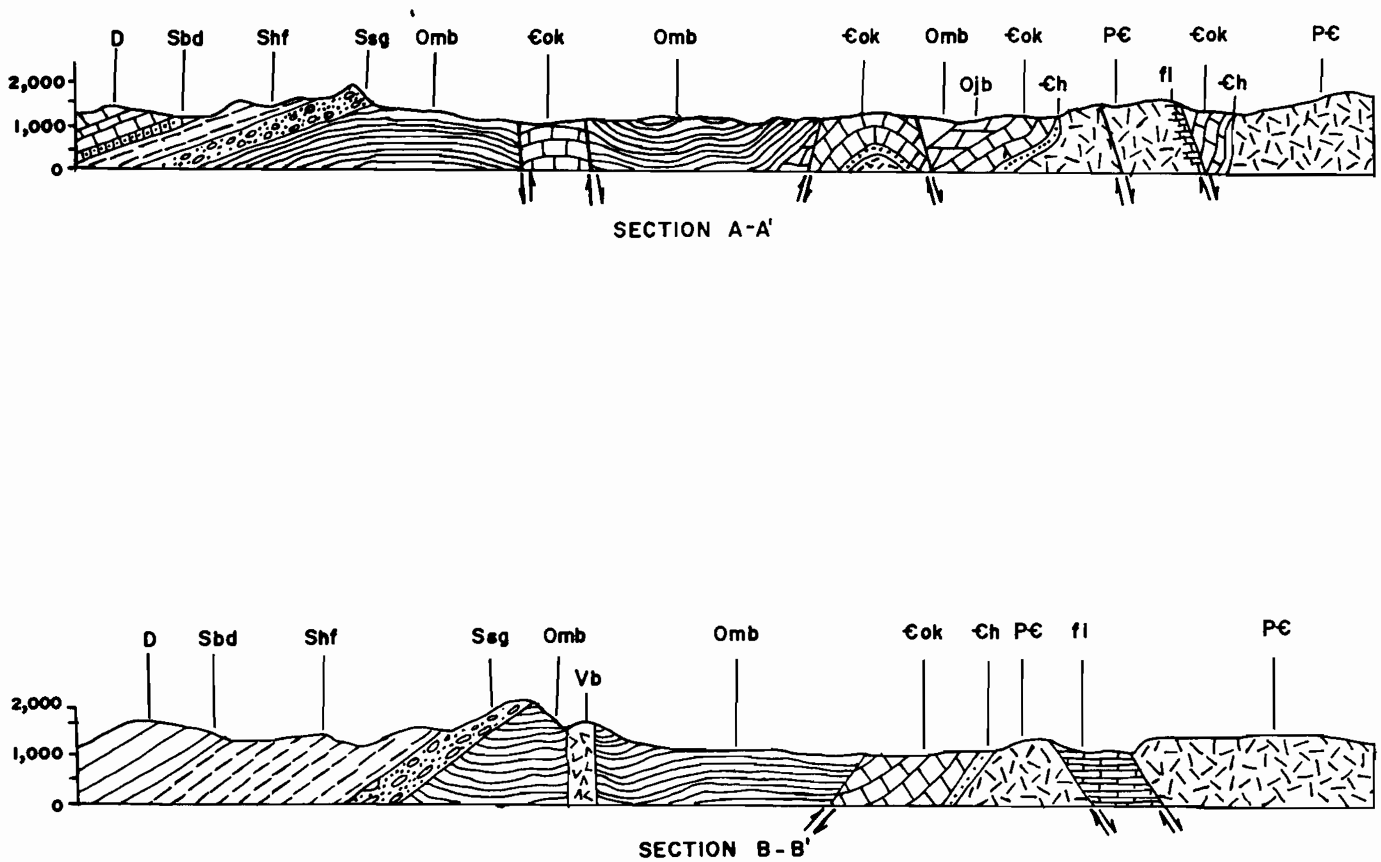
State-------County-------

A———CROSS SECTION———A'

BASE MAP ATLAS SHEET #40

Source: 208 W.Q. Management [illegible]n 4/79

FIGURE 7



GEOLOGIC CROSS SECTIONS

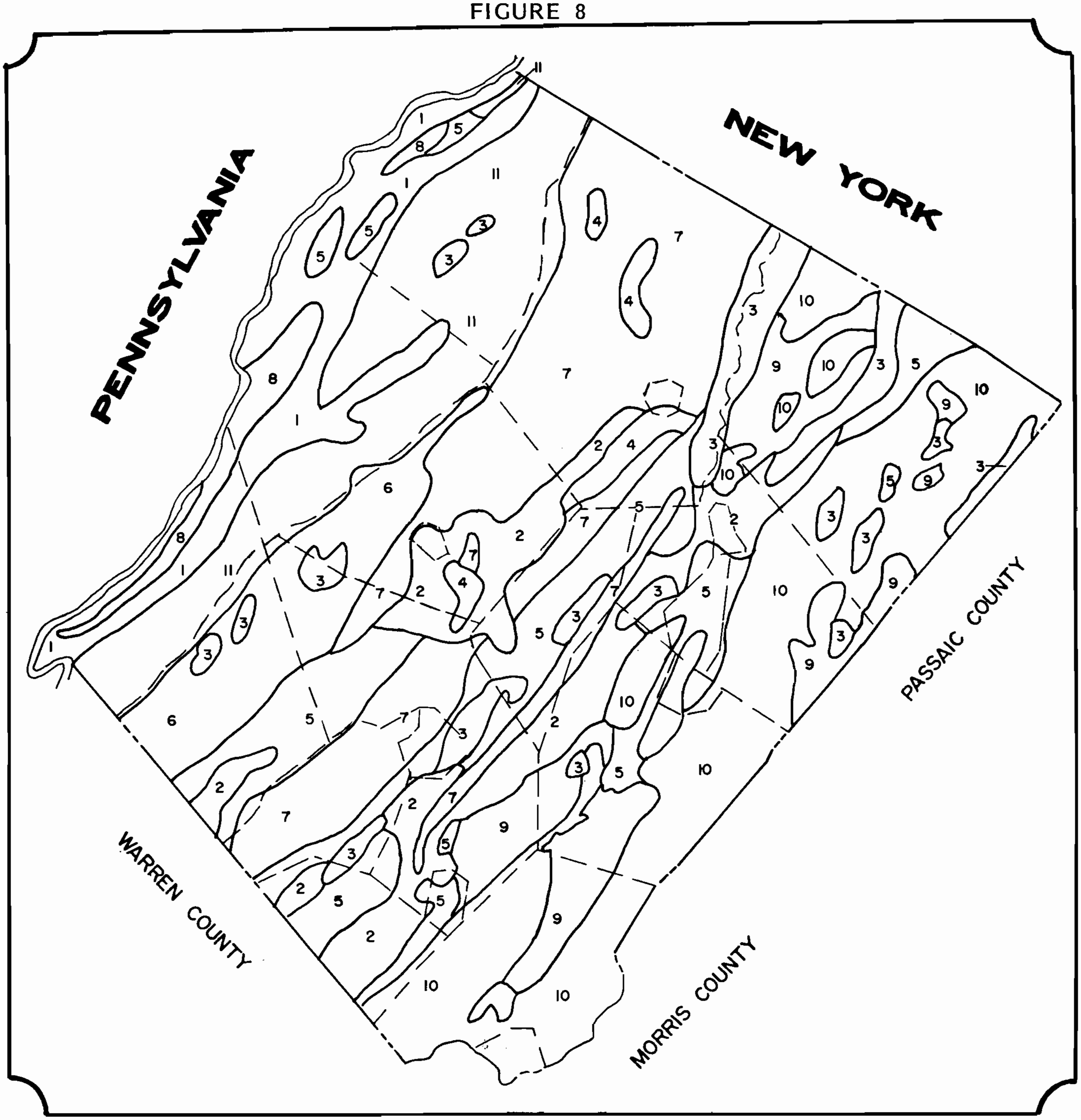
LEGEND

D	Devonian limestone, shale & sandstone	Ojb	Jacksonburg Formation
Sbd	Silurian limestone & shale formations	€Ok	Kittatinny Formation
Shf	High Falls Formation	€h	Hardyston Quartzite
Ssg	Shawangunk Conglomerate	vb	Volcanic Breccia
Omb	Martinsburg Formation	fl	Franklin Formation
		P€	Precambrian (undifferentiated)

New Jersey Geological Survey 1967
Horizontal Scale: $1\frac{1}{2}$" = $2\frac{1}{2}$ Miles
Vertical $\frac{1}{8}$" = 500 Feet

Source: Lewis & Kümmel, Geologic Map of New Jersey

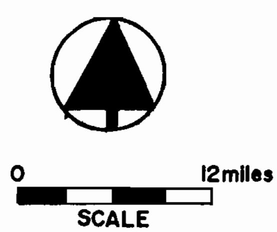
FIGURE 8



SOIL ASSOCIATIONS

LEGEND

1. Chenango-Atherton-Braceville
2. Hazen-Palmyra-Fredon
3. Carlisle-Swamp
4. Livingston-Sloan-Wayland
5. Washington-Wassic-Rock outcrop
6. Swartswood-Nassau
7. Nassau-Bath-Norwich
8. Wassic-Wooster-Rock outcrop
9. Rockaway-Hibernia-Whitman
10. Rockaway-Rock outcrop-Whitman
11. Rock outcrop-Oquaga-Swartswood



Source: U.S.D.A., Soil Conservation District

Hydrologic Characteristics of Geologic Formations[11]

The most relevant aspect of geology and soils to this manual is how they combine to yield groundwater. The hydrologic properties of the common water yielding rock formations in Sussex County will now be discussed in detail.

Precambrian Crystallines and Hardyston Quartzite:

Practically all groundwater in these formations occurs in joints and faults. In areas where the joints are far apart there may be no distinct water table per se and each system of joints has its own level. The most abundant fractures and the weathered zone occur at depths of less than 150 feet below the surface. Extensive weathering may also occur in fault shear zones and in areas of closely spaced open joints. These areas have a large water storage capacity and can yield considerable amounts of groundwater (See Table II).

Kittatinny Limestone Formation

Although this formation has been shown on Plate 1 as a single unit, it is actually comprised of five major subgroups which are broken down into a total of twelve members, each with different water holding capacities (see Figure 9). Figure 10 shows these members in cross sections from east to west and displays the relationship between topography and the underlying geologic formations.

The Kittatinny Formation in general, offers no primary porosity but does store significant volumes of water through joints, fractures, and solution cavities within the rock. The joints, fractures and solution cavities become expanded as rain, which has accumulated carbon dioxide in the atmosphere forming a weak carbonic acid, percolates down through the soil picking up organic acids. The slightly acidic solution then finds its way into joints and fractures, slowly dissolving the limestone until large channels and caverns are formed.

Solution channels are more commonly found in valleys, depressions, and near streams and rivers.[11a]. However, there is no way to accurately predict their distribution within the rock. Occasionally, when voids in the cavernous formations are not filled with groundwater and the soil overburden can no longer be supported, the limestone sinks under the weight, forming a depression called a "sink hole". This phenomenon can also occur near large diameter pumping wells. A series of sink holes may be aligned along an underground cavern and a well drilled on such a line could very easily produce a large quantity of water, but is subject to contamination from the surface, pointing out the risks associated with improper land use at the surface. Often times solution channels become filled with clay, but extensive pumping over a long period or proper development of the well often produces an excellent well.

11-11a. Joseph Miller, "Geology and Groundwater Resources of Sussex County..", January, 1974, in The '208' Water Quality Management Plan*, April, 1979, pg. X-17*

TABLE II

SUSSEX COUNTY AND THE WARREN COUNTY PORTION OF THE

TOCKS ISLAND IMPACT AREA

SUMMARY OF DOMESTIC WELLS

YIELDS IN GALLONS PER MINUTE

Formation	No.of Wells	Maxi.	Mini.	Average	Median
Stratified Drift (Qsd)	121	75	3/4	17	15
Onondaga Limestone (Don)	69	100	1	19	15
Esopus Siltstone (Des)	13	70	1	9	4½
All Formations					
Poxono Is-Oriskany Form. (Spi-Do)	62	80	2	18	12
High Falls Formation (Shf)	96	60	½	17	15
Shawangunk Formation (Ssg)	15	20	½	6	4
Martinsburg Hornfels (Ombh)	12	18	1	5½	3
Martinsburg Formation (Omb)	919	120	½	10½	6
Kittatinny Formation (COk)	122	120	¼	11	10
Franklin Limestone (H)	162	100	¼	11	10
Precambrian Crystallines (P)	1018	100	¼	10	8

DEPTHS

Formation	No.of Wells	Maxi.	Mini.	Average	Median
Stratified Drift (Qsd)	121	218	35	95	81
Onondaga Limestone (Don)	69	315	35	119	135
Esopus Siltstone (Des)	13	339	98	186	157
All Formations					
Poxono Is-Oriskans Form. (Spi-Do)	62	278	51	122	105
High Falls Formation (Shf)	96	320	36	136	125
Shawangunk Formation (Ssg)	15	306	97	177	158
Martinsburg Hornfels (Ombh)	12	273	101	179	173
Martinsburg Formation)Omb)	919	683	35	169	132
Kittatinny Formation (COk)	422	185	27	138	113
Franklin Limestone (H)	162	520	15	119	130
Precambrian Crystallines (P)	1018	440	35	133	122

Source: Sussex County '208' Water Quality Management Plan, April 1979, page X-25

FIGURE 9

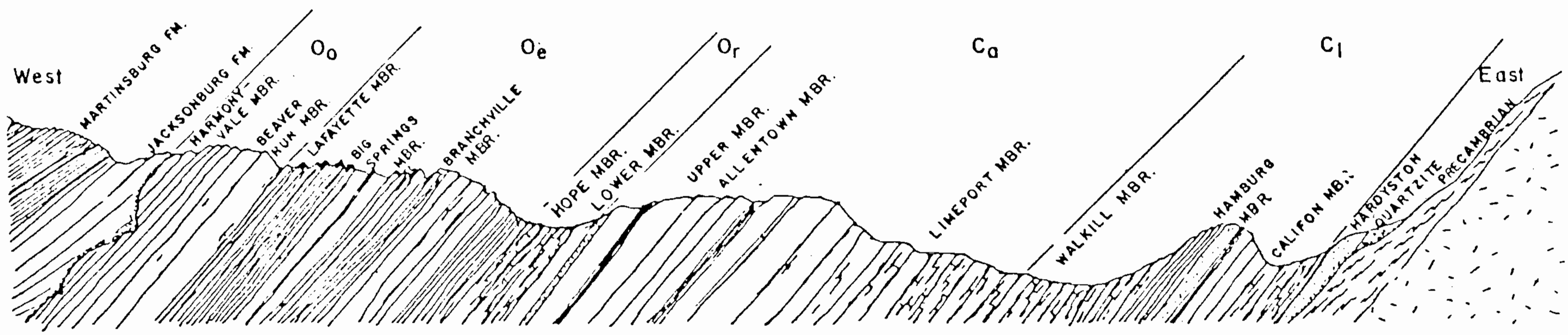
SUBDIVISION OF THE KITTATINNY LIMESTONE

<table>
<tr><th></th><th>Formation Name used on N.J. Geol. Map</th><th>Formations recognized by H.B.Kummel & Others</th><th>Formations Recognized by A.A.Drake & F.J.Markewicz</th><th colspan="3">Current Stratigraphy as used by F. J. Markewicz and R. F. Dalton</th></tr>
<tr><td rowspan="7">LOWER ORDOVICIAN</td><td rowspan="12">KITTATINNY LIMESTONE</td><td rowspan="7">Beekmantown</td><td rowspan="5">Epler</td><td rowspan="2">Ontelaunee Formation</td><td colspan="2">Harmonyville mbr.</td></tr>
<tr><td colspan="2">Beaver Run mbr.</td></tr>
<tr><td rowspan="3">Epler Formation</td><td colspan="2">Lafayette mbr.</td></tr>
<tr><td colspan="2">Big Springs mbr.</td></tr>
<tr><td colspan="2">Branchville mbr.</td></tr>
<tr><td rowspan="2">Rickenbach</td><td rowspan="2">Rickenbach Formation</td><td>Hope mbr.</td><td rowspan="2">Crooked Swamp Dolomite Facies</td></tr>
<tr><td>Lower mbr.</td></tr>
<tr><td rowspan="5">CAMBRIAN</td><td rowspan="2">Allentown</td><td rowspan="2">Allentown</td><td rowspan="2">Allentown Formation</td><td colspan="2">Upper mbr.</td></tr>
<tr><td colspan="2">Limeport mbr.</td></tr>
<tr><td rowspan="3">Tomstown</td><td rowspan="3">Leithsville</td><td rowspan="3">Leithsville Formation</td><td colspan="2">Walkill mbr.</td></tr>
<tr><td colspan="2">Hamburg mbr.</td></tr>
<tr><td colspan="2">Califon mbr.</td></tr>
</table>

The table indicates the present stratigraphy used in New Jersey and its correlation to those formational names used by earlier workers.

SOURCE: OFFICE OF THE STATE GEOLOGIST

FIGURE 10



Idealized East-West Geologic Cross-Section of Cambro-Ordovician "Kittatinny" Carbonate Rocks of New Jersey, Showing Relationship Between Topography and Member Subgroups of the Leithsville (C_l), Allentown (C_a), Rickenbach (O_r), Epler (O_e) and Ontelaunee (O_o) Formations.

SOURCE: OFFICE OF THE STATE GEOLOGIST

Groundwater in the Kittatinny Formation is found under both water-table and semi-artesian conditions. Water tables can be found near the surface, while the semi-artesian situations occur in some deeper solution channels and are recharged by sink holes and water table aquifers.

According to well yield data, the most successful wells of the members of the Kittatinny Formation have intersected large caverns between 50 and 300 feet.[11b] Joseph Miller, in his widely used report on the geology of Sussex County and the portions of Warren County lying within the proposed Tocks Island Dam Project, identifies the Epler or Leithsville member groups as the ones most apt to host wells which would intersect solution channels.[11c] According to the well yield data referred to above, 422 domestic wells pumping from the Kittatinny Formation, produce between ¼ to 120 gpm with an average of 14 gpm.[11d] As a general breakdown; thirty-five percent of the sampled wells yielded 5 gpm or less, fifteen percent yielded between 16 and 25 gpm, and fourteen percent yielded between 26 and 79 gpm.[11e]

Currently, the State Bureau of Geology is completing an extensive mapping project of carbonate rocks in the Hamburg Quadrangle. When available, this information will prove quite valuable to this manual and other groundwater related endeavors.

The Martinsburg Formation:

The Martinsburg Formation has no primary porosity or permeability except in some sandstones and calcareous sandstones. Therefore almost all of the water that is held in these formations is contained in numerous fractures. These fractures in the Martinsburg are considered to be very tight and therefore create a very poor aquifer. Soil cover is often thin on Martinsburg and storage for recharge is therefore reduced and runoff is increased.

The Martinsburg Hornfels:

This formation has no primary porosity and groundwater is found only in vertical cracks and crevices. Because of this condition, there were only twelve domestic wells drilled in this formation as of 1974.[12]

The Shawangunk Formation:

There is some primary porosity in the sandstone members of this formation, but for the most part the formation offers groundwater only in vertical cracks and crevices. There were fifteen domestic wells in 1974, but only nine had sufficient pumping data to summarize.

11b,c,d,e - Joseph Miller, Geology of Sussex County and the Warren County Portion of Tocks Island Impact Area.

12. Sussex County '208' Water Quality Management Program, '208' Water Quality Management Plan, Sussex County Planning Department, April, 1979, pg. X-18

Quaternary (Glacial) Deposits

The evidence of three periods of glaciation, (Kansan, Illinoian, and Wisconsin) can be seen in sediments consisting of river silt and stratified drift in the valleys; till in ground moraine and drumlins (oval shaped hills), terminal and recessional moraines; stratified drift in Kames (steep ridges) and Kame terraces; and glacial lake bed deposits. Although till and glacial lake deposits normally have low permeability because of a higher clay content and inadequate sorting of materials, the stratified drift, if it contains a sufficient quantity of coarse material is an excellent source of groundwater. The reason this glacial drift becomes stratified is because it has become caught up and modified, sorted and deposited by streams of meltwater running away from the glacier.[13] The groundwater systems in stratified drift deposits are the most complex in Sussex County. Most of these deposits hold water in a water table configuration, with the more coarse deposits having the highest permeability and storage coefficients. Some glacial aquifers occur under semi-confined conditions. The recharge of the water table can come from varied sources. Direct precipitation is capable of recharging the water table as are underlying or adjacent rock formations and surface water sources. Although most streams and rivers are fed by groundwater springs, there are times of drought when a reverse recharge situation can occur into stratified drift deposits along their banks and through stream beds. The pumping of groundwater near these surface waters can sometimes induce recharge of stratified deposits by the same means. The water budget is the crucial determinant of these interactions between groundwater and surface water bodies. The inducement of surface water into the water table can only occur if there is a deficit in the water budget due to insufficient precipitation to balance losses from evapotranspiration or over pumping. Table II, which is a summary of domestic well yields in Sussex County done by Miller in 1974 lists the formations discussed in this section. This information can be referenced to the geology map in Figure 6.

The next chapter will identify critical areas in Sussex County and discuss the need for protection and management.

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13. *Joseph Miller, Geology of Sussex County and the Warren County portion of Tocks Island Impact Area.*