W.P.

Groundwater Quantity and Quality in the New Jersey Coastal Zone:

A Staff Working Paper

Michael Hochman

New Jersey Department of Environmental Protection

Division of Marine Services

Office of Coastal Zone Management

P. O. Box 1889

Trenton, New Jersey 08625

November 1976

Note: This staff working paper is one of a series of Issue and Policy Alternative Papers presenting facts, analyses, and conceptual policy alternatives on coastal resources and coastal land and water resources. The purpose of this draft document is to stimulate discussion and comments that will assist preparation of the management program for the New Jersey coastal zone. This report was prepared in part with financial assistance under the Coastal Zone Management Act, P.L. 92-583.

Comments, criticisms, additions, and suggestions are welcome and should be addressed to the Office of Coastal Zone Management.

CONTENTS

Appendices

INTRODUCTION

The loss or severe reduction of our groundwater resources and the danger of local groundwater contamination is a real and potential problem in areas in and adjacent to the coast. The depletion of this valuable, readily available, natural resource and salt water intrusion and local pollution may severely disrupt the coastal population and its economy by limiting potable water supplies.

This paper is intended to further debate on important groundwater issues. The first section briefly defines these issues in the coastal area and then presents alternative policies which could be part of the coastal zone management program in New Jersey.

Section III provides characteristics of groundwater in New Jersey's coastal area in terms of existing and potential quantity and quality.

Section IV analyzes natural processes and man-made activities that affect groundwater quantity and quality.

Two appendices conclude the paper. First, coastal zone regions are examined individually and problems specific to the region are highlighted.

Finally, the sources used to support and reference the text are presented.

I. ISSUE

A. Groundwater Quantity

In some areas of the coastal zone localized scarcity of groundwater is becoming an increasing problem. This applies expecially to the intensely developed areas primarily the Hudson River Waterfront and Newark Bay areas, Monmouth, Salem, and Cape May counties.

Pumping of groundwater and the reduction of aquifer recharge by the construction of storm water drainage systems that discharges into surface water, has led to a scarcity of groundwater in localized parts of the coastal zone. If the trend of groundwater depletion continues it will lead to a loss of economic benefits resulting from the loss of a cheap high quality water supply. There is also a side effect of overpumping and consequently lowering of the water table that could change the base flow conditions of streams altering the ecological conditions of an aquatic environment.

B. Groundwater Quality

The quality of groundwater supplies in the Coastal Zone has been locally threatened in recent years by contamination from man-made pollutants to the water table aquifer. This has resulted in the abandonment of many wells.

Secondly, salt water intrusion threatens groundwater existing along the immediate Atlantic Coast over most of the

Coastal Plain.

Saltwater has already contaminated some water supplies along the coast and some wells have had to be abandoned. Increasing population and concentrated development will eventually worsen the situation. This will result in the loss of economic benefits because of the forfeiture of a cheap water supply.

II. POLICY ALTERNATIVES

Planning and regulations are needed to maintain an ample supply of groundwater.

1. The safe sustained yield of local aquifers should be established. This is the amount of water that can be constantly withdrawn without unacceptable change to water table elevation and salt water intrusion. This data can be partially obtained from the digital computer simulation model that USGS has been undertaking. Aquifer models have been completed and calibrated for the following aquifers within the coastal zone: Raritan-Mogothy, Englishtown and Wenonah-Mt. Laurel. This model will show the best location of wells and quantity of withdrawal.

   In order to assure the safe sustained yield the following should be included:

   (a) protection of prime recharge areas

   Prime recharge areas could be delineated. Criteria for such a delineation would include: permeability of soils, land cover, depth to seasonal water table, elevation of the area and geology.

   Development over these areas could be required to respect the recharge conditions of the soils and geologic formations. Standards would include limitations to the amount of impermeable surfaces that water retention basins and/or constrction of wells to artificially recharge endangered groundwater aquifers. This is being done in Long Island, New York.

(b) Proper placement of new wells on the areas not covered by aquifer models

Placement of new wells could be based on groundwater availability and quality. Criteria would be specific to different areas and include: the number of wells to be drilled and the amount of water allowed to be pumped from each well-theoretically derived safe sustained yield, and the placement of wells in relation to each other.

Spacing requirement should, whenever possible, be based on local factors because no one set of distances will be adequate and reasonable for all conditions. In areas where "undesirable" conditions exist safe distances should be extensive. In areas possessing especially "favorable" conditions lesser distances might be acceptable if approved by the enforcing agency.

In the determination of the factors which will govern the selection of a safe distance the following mimimun factors should be evaluated: the type and location of the sources of potential and existing contamination; geologic and hydraulic characteristics of the material between the land surface and water table, the water table and bedrock, seasonal depth to water, its direction and rate of movement, and the mathematically derived effect of well pumping on the direction of groundwater movement between the source of contamination and the well.

2. Preventive and remedial measures could be taken to control saltwater intrusion. Some of the threatened areas are identified by USGS and delineated, thereby action could be taken in these areas to combat salt intrusion. Measures taken could include wells drilled to artificially recharge endangered aquifers to maintain a pressure head so as to control saltwater intrusion, and stringent regulations concerning the utilization of groundwater overpumpage of aquifers threatened by intrusion. Also, construction of tidal dams to maintain freshwater storage in the reaches of streams that are subject to saltwater flooding during high tide and severe storms.

3. More stringent regulations should be developed concerning point and non-point pollution sources and their relationship with recharge of aquifers. Minimum distances should be set between sanitary landfills and wells. Certain types of materials

such as industrial wastes, dredge spoils etc. to be dumped should be regulated in prime recharge areas.

The inventory of non-point pollution sources affecting groundwater in the coastal zone would lead to measures resulting in the amelioration of specific non-point pollution impacts. For example, soil and conservation practices are one of the most effective principal controls for reducing potential pollution from agricultural watersheds (see Water Quality Issue Paper).

III. PHYSICAL CHARACTERISTICS AND NATURAL FUNCTIONS

Portions of two geologic provinces of greatly differing water-bearing capacities are located within the New Jersey Coastal Zone, Figure 1. Differences exist because the geologic formations enclosing each province contrast greatly in their ability to receive and to store water.

The northern province, the Piedmont Plateau, which includes the Hudson River Waterfront and Newark Bay, is composed of consolidated material where the majority of its groundwater is retained in the hard, extensively fractured, sedimentary rocks. The thinner and less pervious soils and steeper slopes, permit less infiltration, perhaps one-fourth to one-third as much as in South Jersey, and the average time before the shallow groundwater appears in the streams is much less. Local anomalies provide no water, such as the basalts of the Waychung Mountains. Large amounts of groundwater also exist in the uncosolidated glacial drift occupying ancient river valleys. Glacial deposits of unsorted material, ranging from clay particles to large boulders, from sheets of unconsolidated drift that cover much of the Piedmont with a depth of 15-20 feet. However, the drift-filled valleys may be hundreds of feet deep and the aquifers within them can, if impermeable layers of clay and marl overlie them, become artesian.

The New Jersey portion of the Atlantic Coastal Plain is composed of unconsolidated silts, clays, sands, and gravels. It is bounded on the north by a line stretching from Trenton to Raritan Bay and includes three-fifths of the State. It stretches 100 miles outward into the Atlantic Ocean.

Perhaps 40 percent of out 45 inches of precipitation falling each year on the sandy Coastal Plain would infiltrate into the ground and most of that would reappear days, weeks, or months later in the springs or seeps that feed the streams.

There is recharge to two physiographic provinces of the Coastal Plain, Figure 1;

1. In the area of the Inner Coastal Plain there is recharge to the large capacity sand formations, true aquifers. These aquifers outcrop along the Atlantic Coast north of about Neptune City up to Sandy Hook and around the Raritan Bay and also the area of the coastal zone up-river from Lower Alloways Creek.

   The aquifers dip gently to the southeast from the outcrop area and underneath the Outer Coastal Plain's impermeable layers of clay and marl that prohibit the flow of water through them. The water exists under pressure. Wells are drilled through the Outer Coastal Plain to great depth to tap these formations, see Figure 2.

2. The Outer Coastal Plain, larger in the area than the Inner Coastal Plain, has at the surface Pleis-

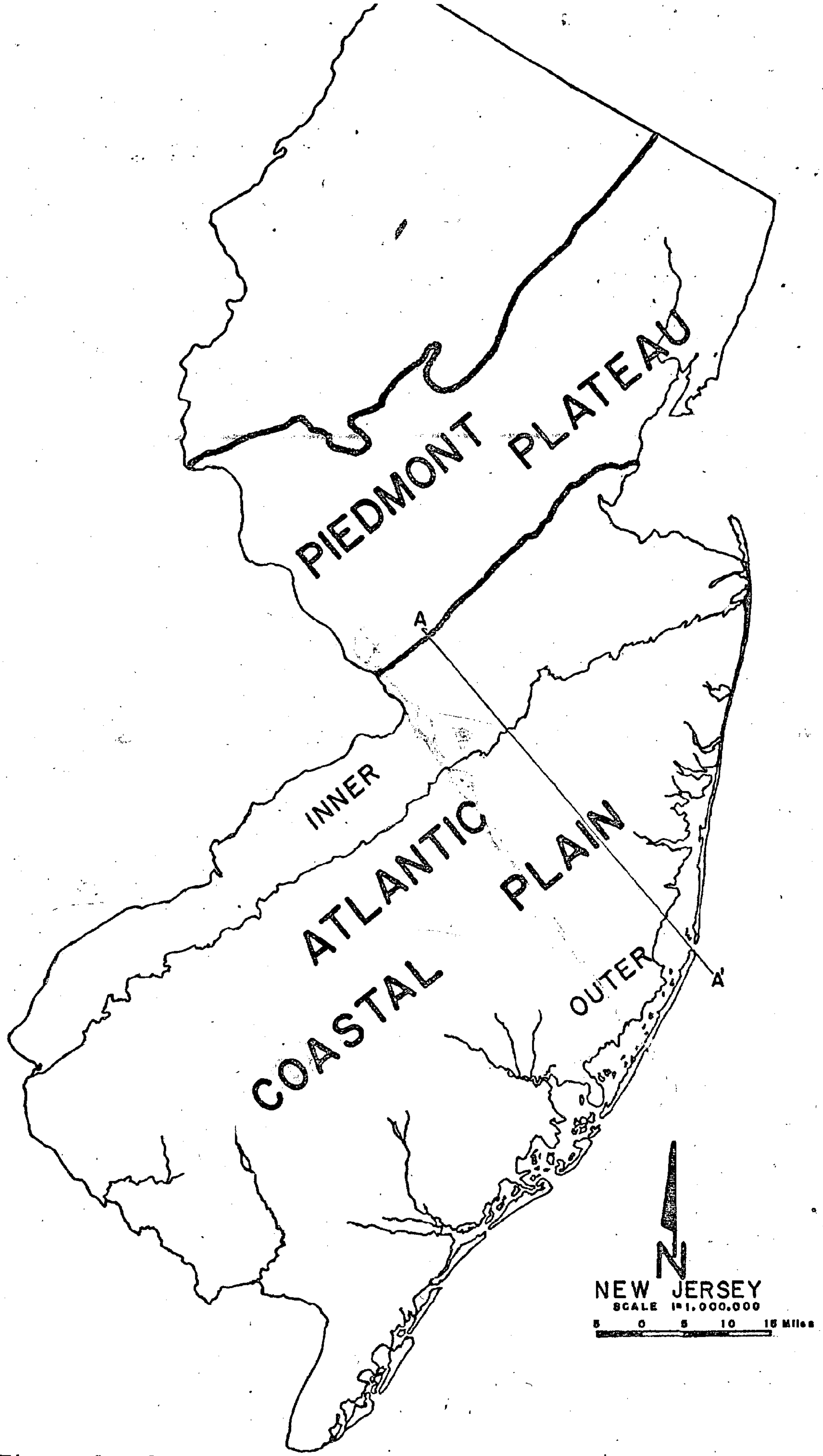

Figure 1. Physiographic provinces in the coastal area of N.J.

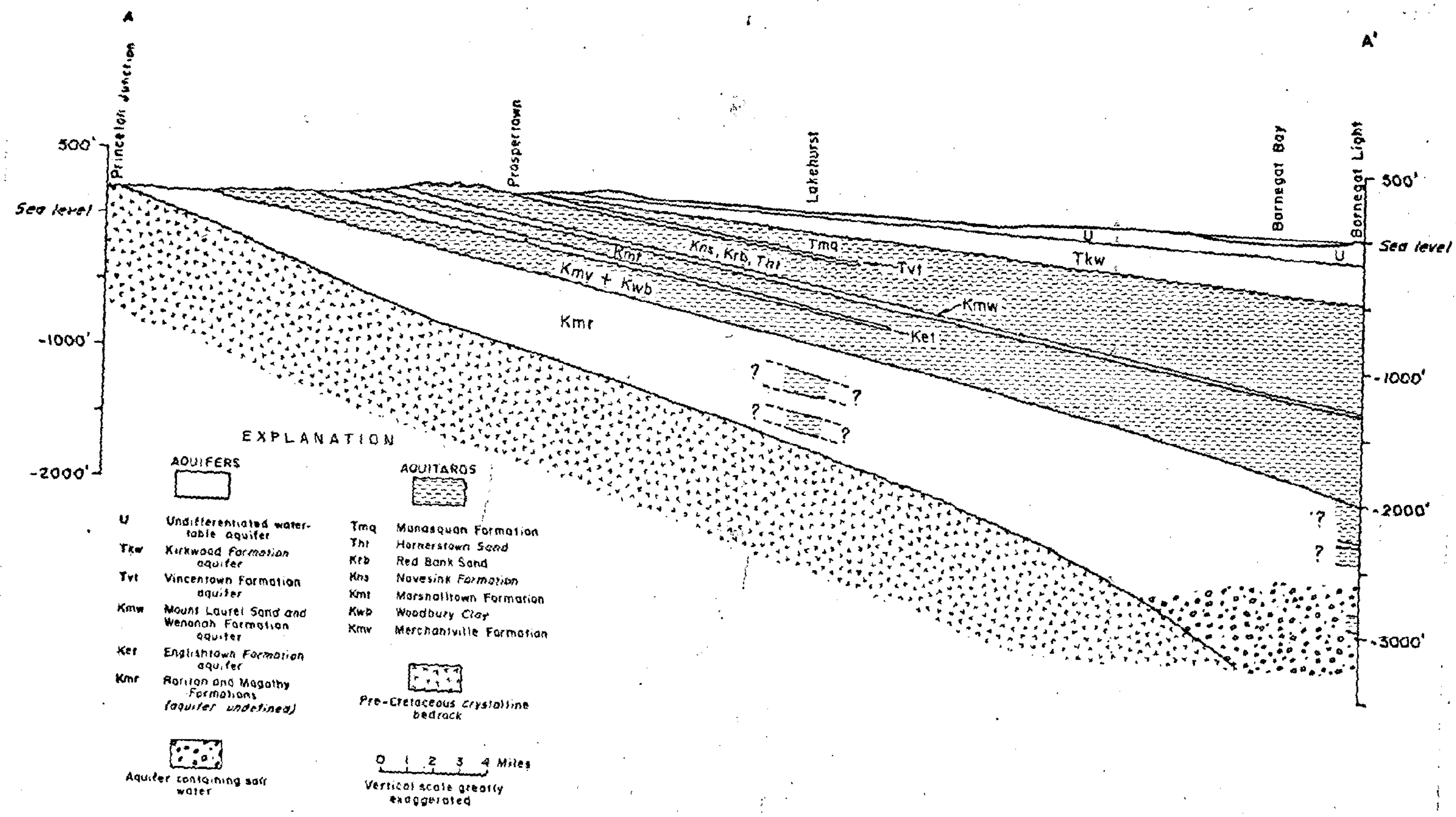

Figure 2. Geohydrologic Section, Coastal Plain.

tocene sand and gravels, the Cohansey Formation, and the underlying Kirkwood Formation all of which are essentially acting as one hydrologic unit. While there are areas underlain by clay or with appreciable silt or clay in the sands, which therefore are not as good for percolation of rainfall, most of the area is a sand which will absorb about 1/2 inch per hour of rainfall. Therefore, unless the ground is frozen there is practically no surface runoff because rain storms seldom exceed this hourly rate.

This unconfined or semi-confined unit, receives almost all initial recharge from precipitation and streams. It then may recharge underlying aquifers through direct contact or breaks in overlying layers of impermeable clay and marl.

The sandy Coastal Plain is water-bearing to thicknesses of 6,000 feet above bedrock near Cape May but thinning down from 30 to 50 feet above bedrock along the Delaware River and along the fall line from Trenton to Perth Amboy. In the Coastal Plain some of the large wells are screened at depths of 600 to 800 feet, but most are less than 300 feet deep.

In total, some 22 to 25 inches of out 45 inches of rainfall is lost each year to evapotranspiration of deep percolation to the oceans. The remainder, which may vary from 8 inches in a drought year to 35 inches in the wettest years, runs off through the groundwater-surface stream system to the ocean. It is worthy of note, however, that evapotranspiration takes first claim on precipitation and does not vary greatly from a dry year to a wet year in New Jersey. The residual 8 to 35 inches, averaging about 21 inches, is available for immediate use by man or for storage above or below ground. We are only withdrawing about one-fourth of the 21 inches of annual precipitation not claimed by evapotranspiration. A much larger proportion could be withdrawn with additional surface storage and greater use of groundwater in areas of surplus. If groundwater is not used, its potential is not realized and storage space under-ground is not created into which precipitation can infiltrate to replenish the supply. If pumping exceeds the natural recharge rate for long periods, then groundwater levels drop, but this is only happening in a few centers of heavy pumping.

New Jersey Coastal Zone groundwater quality at a given place is very constant from day to day and year to year. However, over the State there are areas of salty water (perhaps 10 percent ~~of total~~ volume), pockets of high iron content, very hard water, or high in content of other dissolved minerals, see Table 1. All except the salty water is potable after conventional treatment and perhaps one-third is potable without treatment. Chlorination and softening, if needed, are the only treatment given to most groundwaters used for public supply, though some is also treated for iron removal.

Table 1.

Range of Impurities in the Following Coastal Zone Aquifers:

Raritan and Magothy Formations, Englishtown Formations, Wenoah Formation and Mount Laurel Sand, Kirkwood Formation, and water table aquifers.

	U.S. Public Health Standards	Range of Impurities Maximum	Range of Impurities Minimum
Iron	0.3	114	0
Bicarbonate	-	382	0
Sulfate	250	465	0
Chloride	250	6800	1.8
Nitrate	20	82	0
Dis. Solids	500	3440	14.0
pH	-	9.1	3.8
Hardness	170	345	2.0
Temperature	-	86 F	41 F

* units in parts per million (ppm)

Source: USGS Special Reports

Groundwater is ecologically vital to the Coastal Zone. It is the source of most stream flow within the zone. All freshwater ecosystems are dependent on groundwater to provide a unique aquatic environment associated with lakes, rivers, and streams. Groundwater is also the primary water source for most terrestrial vegetation and human consumption.

IV. ANALYSIS

A. Groundwater Quantity

The artificial removal of large quantities of water (over-pumping) from the aquifers has no doubt altered considerably the pattern of movement in them. Increased water development may be expected to cause additional changes. The removal of water from an aquifer by a well, or well field, lowers the head around the well enough to induce the flow of an equivalent quantity of water toward the well. The depression of head around the well is called the cone

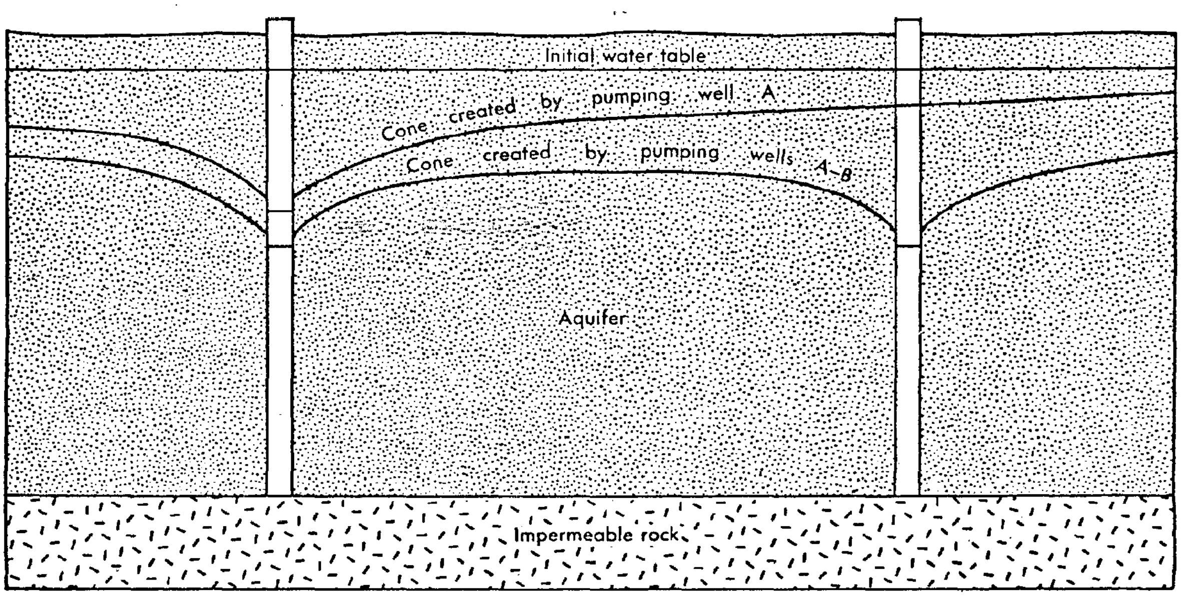

Figure 3 - Cones of depression.

Therefore, the cone of depression of each new well must expand until it has induced additional recharge to the aquifer or intercepted discharge equal to the quantity of water removed by the well. The process may take a considerable period of time because of large quantities of water may be removed from storage in the aquifer and in the adjacent aquicludes. When the process has been completed, however, new flow lines have been diverted from their original courses as water moves toward the well.

Impervious surfaces and construction of storm water drainage systems reduce the amount of rainwater infiltrating into the ground, Table 2. The water flows overland to nearby streams instead, consequently, heavy pumpage creates permanent cones of depression.

TAble 2: Impervious Surface and Storm Sewer of Residential Development.

Development Type	Amount of Impermeable Surfaces	Storm Sewered
1 DU/2 Acres	5%	–
1 DU/Acre	10%	-
2 DU/Acre	20%	20%
4 DU/Acre	33%	33%
8 DU/Acre	50%	50%

8 DU/Acre	75-100%	50-100%
Clustered		
Urban	10%	

Source: Caputo, Hochman, and Hougen, 1974

The present state of groundwater resources show in localized areas a reduced level of water due to pumping and to a much lesser degree development of our recharge areas. Based on available data, groundwater levels will continue to decline at the present rate of usage. The possibility exists that water supplies in some areas could fall short of demand and this is more likely in the event of a prolonged drought. Planning is needed to ensure an ample supply of groundwater from the coastal zone in the future.

B. Groundwater Quality

Man's activities constitute the prime source of the contamination of groundwater aquifers. There exist two major categories of pollutants, man-made pollutants and man-induced pollutants. Contamination of aquifers with man-made point source pollutants occur when pollutants exist on the surface which are capable of seeping into the ground with recharge from precepitation. Permeable soils are more susceptible to seepage than soils containing a significant proportion of silt and clay. Potential pollutants may be found in sanitary land fills, sewage waste disposal sites (see the Solid Waste Issue Paper for specifics), septic tanks. Figure 4 shows the introduction of contaminants into an aquifer from a septic tank.

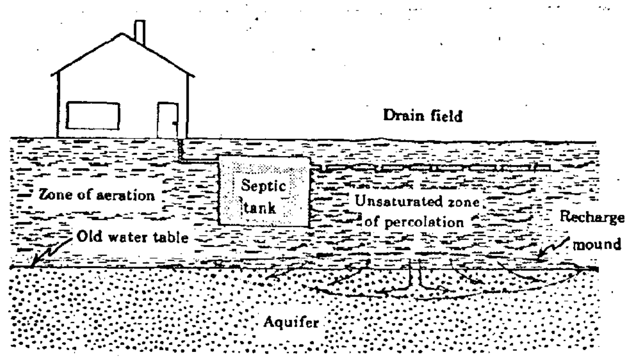

Figure 4. Percolation through zone of aeration. Most of the natural removal or degradation processes function under these conditions.

Common biological wastes are naturally removed by those processes that operate under condition of aeration. Almost all of the suspended solid material is filtered out by the upper few inches of soil. However, stable contaminants in solution such as phenolic compounds or synthetic detergents may still percolate through the aquifer to a well.

Contamination of aquifers from man-made non point source of pollution comes from polluted streams that recharge groundwater aquifers, agriculture roads, air borne wastes.

Figure 5 represents a major problem facing those water users with heavy pumpage near polluted streams. If a stream that is the source of water for a well field is contaminated by materials that are not naturally degraded under saturated underground flow conditions, groundwater in the vicinity of the well will in turn be polluted.

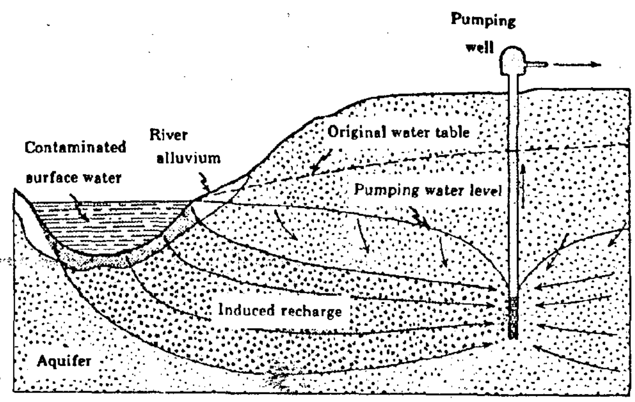

Figure 5. Induced infiltration from stream. Stream pollution can result in "groundwater" pollution. Natural purification is limited to those processes requiring no oxygen.

There are two classes of potential pollutants from agricultural cropland. These include sediment, and agricultural chemicals. Sediment may be one of the most costly and serious of all pollutants from agricultural cropland, although it is often overlooked. The importance of sediment as a pollutant comes from the high costs resulting from sedimentation and filling of streams, causing reduction in carrying capacity, and increased possibility of flooding.

Agricultural chemicals, including modern pesticides and chemical fertilizers can be carried off of crop land in two forms: (a) soluble forms in runoff or in percolate water, (b) insoluble forms or attached to colloidal sediments.

Roads and highways, collect oil and gasoline spills, tire tread dust etc. Precipitation will wash off the pollutants and runs off as overland flow. A part of water entering the roads percolates downward to the soil zone and eventually to the water table.

The airborne substances such as chromium can be introduced to the aquifer in several ways. For instance, chrome-laden dust from an electroplating company is discharged through ventilators on the roof. Some of the dust settled to the ground, where it accumulated until rainfall washes it down to the water table, as dipicted in Figure 6. A general relationship is shown between precipitation and chromium contamination in the township wells.

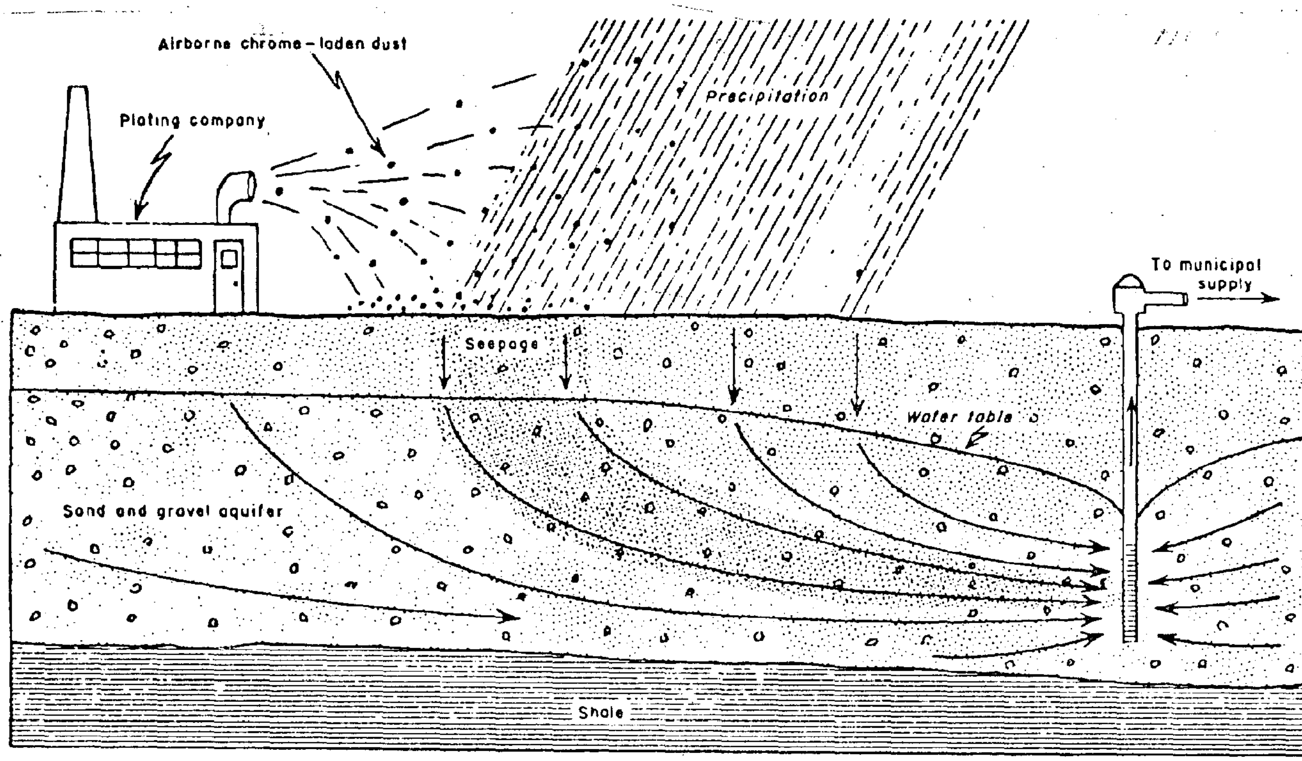

Figure 6. Diagram showing possible mode of entry of airborne wastes to aquifer.

Naturally occurring salty or mineralized water may be redistributed and may flow into fresh-water aquifers. This salt-water intrusion, a man-induced pollutant, occurs when pumping wells near the sea or near coastal bodies of salty water may cause an inflow of salty water if the hydraulic head in the fresh-water aquifer is depressed sufficiently to cause the salty water to move toward the center of pumping, see Figure 7.

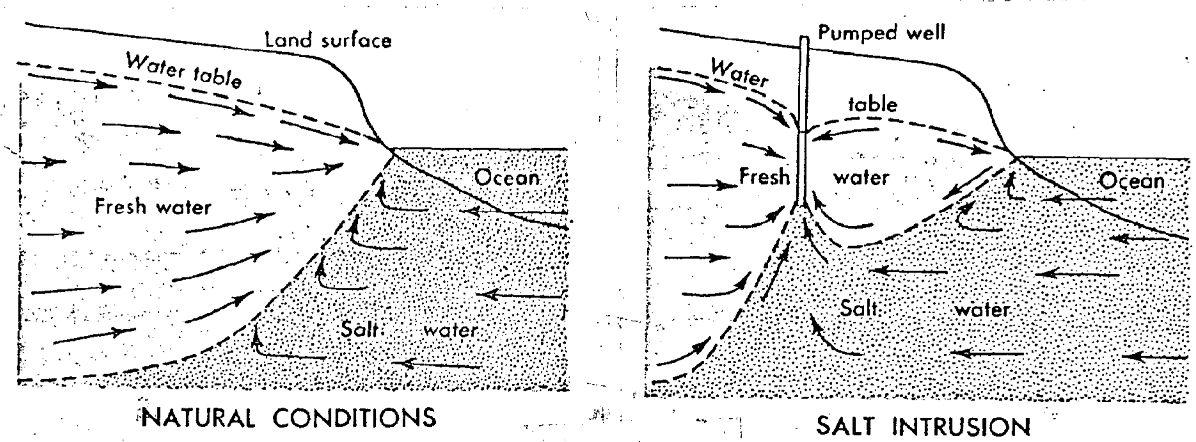

Figure 7.

Along the coast and even inland where salty water underlies freshwater aquifers, pumping and consequent reduction in hydrostatic pressure in the freshwater aquifer may cause the underlying salty water to move upward.

Where salt or brackish surface water is in contact with a freshwater aquifer along some reaches of the Delaware River, as an example, it will enter the aquifer if the head of the freshwater is low enough to permit it. On the other hand, if the fresh water head is high enough, there will be a flow of freshwater out of the aquifer, and no salt water will enter.

Under natural conditions the freshwater-saltwater interface is usually stable with only very severe droughts perhaps affecting the salt line. But man has created an inbalance by pumping out water near the saltwater line and building impermeable surfaces increasing surface runoff and therefore decreasing groundwater recharge. Both of these factors lessen the hydraulic pressure of the freshwater allowing for the intrusion of saltwater into the aquifers. The dredging activities in the Delaware River involving the clearing and maintenance of shipping channels and the construction and maintenance of harbor facilities also has a large affect on the nature of the aquifers, especially Raritan Magothy aquifer.

Since the Raritan Magothy formation outcrops underneath the Delaware River the maintenance of a ship channel to a depth of at least 40 feet can cut into the Raritan Magothy, allowing river water and its pollutants to flow unimpeded into the aquifer. Also, the impact of dredging includes placing of dredge spoils on the land where the aquifers outcrop.

The quality of groundwater in the Coastal Zone has in some areas been steadily decreasing due to contamination, especially saltwater intrusion. No change is expected in the future with the continuance of unrestricted pumping of water and dumping of pollutants. Contamination of water supplies of the heavily developed Coastal Zone is where salt intrusion is most likely to occur. It is possible that in the future some communities will not be able to meet their own water demand. Proposed sludge landfill sites and continued hazard dumping of chemicals will pose other groundwater problems. Therefore, the need exists for more careful planning and management for our groundwater resources.

APPENDIX A
REGIONAL REPORTS

1. HUDSON RIVER

A. Essex County

Physical Characteristics

Groundwater in Essex County occurs in joints and fractures in consolidated rocks of the Brunswick Formation and in the voids of unconsolidated stritified drift deposits.

Rocks of the Brunswick Formation are the main source of groundwater in Essex County. They are generally capable of sustaining moderate to large yields to wells.

Except for hardness and local salt-water contamination water from these rocks is acceptable for consumption.

In the Newark area, salt water contamination has seriously impaired the quality of groundwater and chloride concentration are as high as 1,900 ppm.

Unconsolidated sediments of Pleistocene age mantle the bedrock throughout much of Essex County. Water occurs under water table and artesian conditions. Water table condition occurs where sand and gravel deposits are not covered by clay, silt, or glacial till and are exposed at the surface. They are commonly less than 20 feet thick and do not yield large quantities of water. They are recharged directly from precipitation on the outcrop area. Artesian groundwater occurs where sand and gravel deposits have been covered by lake or silt, or by glacial till. These deposits are largely confined to the buried valley so they are not visible on the surface and their regional extent and distribution are therefore not readily apparent. They are recharged by leakage through overlying confining beds and by precipitation falling on outcrop areas outside Essex County. Some recharge may also be derived from the underlying and adjacent Brunswick Formation.

The average yield is 908 gpm which makes it the most productive aquifer in Essex County.

Water ranges in hardness from 104 ppm to 212 ppm. Most of the samples analyzed had sulfate concentration of 40 ppm or less, chloride -11 ppm and nitrate concentration of 3 ppm or less.

Analysis

Groundwater has high chloride concentrations in areas of relatively heavy pumpage in eastern Newark adjacent to Newark Bay and the Passaic River. Heavy groundwater withdrawals have lowered the general water level in these areas, reversing the natural gradient between the ground and surface water bodies, and have induced a flow of salt water from the river and bay into the underlying water-bearing formations. A probable contributing factor in salt-water intrusion is the dredging of ship canals in Newark Bay and the Passaic River. In deepening these canals, semimpervious Recent and

Pleistocene sediments were removed which had acted as an imperfect barrier to the infiltration of salt-water.

The most highly developed part of the valley - fill aquifer system is in western Milburn and southwestern Livingston. Four well fields tapping the Pleistocene sand and gravel are located in an area of less than 4 square miles. With such spacing of wells and continued heavy development has, naturally, lowered water levels in the aquifer in addition with reduction in the amount of available recharge and extended dry periods, especially from 1961 to 1966.

The localized higher concentration of sulfate, chloride and nitrate suggests a low-grade pollution problem, probably resulting from either sewage or the use of chemical fertilizers in the area.

B. Rahway Area

Physical Characteristics

The Rahway area occupies 67 square miles of the Pedmont Plateau and Coastal Plain. Groundwater in the Rahway area is stored in the glacial drift, Raritan Formation and the Brunswick Shale.

Brunswick Shale yields water from fracture openings and from pore spaces in the interbedded sandstone. The average yield of wells is 75 gpm. Recharge to the Brunswick occurs through the hydraulically continuous overlying drift. Both water - table and artesian conditions exist in the Brunswick Shale. Artesian conditions occur generally at depths greater than 100 feet; water table conditions occur at shallower depths. Groundwater is locally high in sulfate, dissolved solids, and hardness. Brackish water is contained in the Brunswick Shale along the tidal reach of the Rahaway River and northward along the Arthur Kill.

The Raritan Formation overlies the Brunswick in the southeast corner of the area and covers about 9 square miles. The Raritan Formation is a series of clays and sands of about 100 feet in thickness in the outcrop area. The average yield of wells is 96 gpm. The quality of the water is good for most uses with the exception of salt-water encroachment adjacent to Arthur Kill.

Glacial drift mantles the Brunswick Shale and the Raritan Formation and forms the land surface of the area. The drift has an average thickness of about 25 feet. The stratified drift filling the buried valley in Rayway is the only important aquifer of Pleistocene age in the area. The average yield is 370 gpm. An important function of glacial drift is to absorb, store, and transmit water to the underlying shale wherever they are hydraulically connected.

The quality of water is good, however there is potential threat of salt-water encroachment during extended dry periods and high tides encroaching farthest inland.

Analysis

If additional large groundwater supplies are developed in the Rahway area, existing supplies would probably be reduced, and intrusion of salt water could result. In the Brunswick Shale, over development would greatly lower water levels in the southeastern half of the area. To insure a supply of fresh groundwater in the Brunswick Shale, wells should be located where the piezometric surface is 20 feet or more above sea level. Salt water would not be expected at depths of less than about 800 feet in such areas, however, this should be verified by test drilling prior to any additional large-scale development.

Further development of groundwater from the Raritan Formation is limited by the danger of salt-water intrusion. The pumping of wells along the Arthur Kill, forced many industries to obtain water from inland public-water supply companies because of drawn in salt-water. Further pumping would follow the salt-water intrusion path soutwestward from Sewaren where the Raritan Formation is exposed to the Arthur Kill.

Salt-water contamination can occur in the glacial drift along the river banks during high tide if withdrawal of ground-water from stratifed drift and the Brunswick Shale should lower groundwater levels below river level. River water would, then, seep into the groundwater reservoir.

2. North Shore

A. Monmouth County

Physical Characteristics

The principal aquifers underlying the county occur in the Raritan and Magothy Formations, the Englishtown Formation, the Wenonah Formation and Mount Laurel Sand, the Vincentown Formation, and the Kirkwood Formation. They crop out in bands trending northeast-southwest and slope downward toward the southeast. Thickness, pumpage, and water-bearing characteristics of these aquifers are summarized in the table 4.

Aquifer	Thickness (feet)	1958 Pumpage (mgd)	Water-Bearing Characteristics
Raritan and Magothy Formations	25-70	12.3	Most important aquifers. Yields range from 100 to 1,400 gpm to large-diameter wells.
Englishtown Formation	30-50	4.0	Average yield 25 gpm. Maximum reported yield 640 gpm. Average yield to large-capacity wells 410 gpm.

Wenonah Formation and Mount Laurel Sand	30-50	.65	Considered a single aquifer. Average yield 10 gpm. Maximum reported yield 335 gpm.
Red Bank Sand	40	-	Yields range from 3 to 30 gpm to domestic wells.
Vincetown Formation	50-110	-	Numerous domestic wells tap this aquifer-yields range from 10 to 50 gpm.
Kirkwood Formation	0-79	1.5	Yields range from 15 to 1,200 gpm.

Analysis

The Raritan and Magothy Formations may be in hydraulic connection with the Atlantic Ocean and development could be limited by the threat of salt-water encroachment. Studies indicate that salt-water is present in the oceanward extensions of the aquifer, perhaps about 4 or 5 miles offshore prior to large-scale development. Water samples from a test well drilled about 20 miles south of Sea Girt indicated salt-water contamination of the lower part of this aquifer. Until the actual location of the salt water in the aquifer to the east of the county is known, development should proceed with extreme caution.

The area most favorable for additional development of the Raritan and Magothy Formations probably is the western part of the county, where pumpage would aggravate the salt-water problem less than would the same intensity of development in the eastern part of the county. Salt water probably is advancing toward coastal parts of the county in response to existing development. Increased development along the coast would accelerate the rate of advancement toward the coast much more than would the same intensity of development in the western part of the county. Jersey Central Power and Light has wells on Coniskunk Point which originally were fresh water but have turned salty. The Village of Keyport placed their production wells too close to the ocean and they are now very high in chlorine. The area most favorable for additional development of the Englishtown Formation and Mount Laurel Sand is locally in the vicinity of their outcrop areas southwest of the Sandy Hook Bay where water levels are highest and the threat of salt-water encroachment is less. A number of the municipalities in northeastern Monmouth County have been granted diversion rights for wells in the Englishtown Formation which far exceed the ability of this formation to replenish itself in the area of greatest use. Newer wells are going to deeper formations with the same situation occurring, if not properly controlled.

The Red Bank Sand may not be practical to attempt to develop large-yield wells from this aquifer. However, wells located near streams or ponds that are in hydraulic connection with the aquifer may permit large yields, assuming that the streams or ponds are free of contamination.

Probable favorable additional development in the aquifer of the Vincentown Formation occurs locally in the vicinity of the outcrop area and away from the Atlantic Ocean.

The Kirkwood Formations underlies about 25 percent of Monmouth County and makes up the principal water-table aquifer in the southeastern part of the county. Favorable additional development in areas where its saturated thickness is at least 30 feet and remote from saline surface-water bodies.

The hydraulic characteristics of the suboceanic extensions of these aquifers have a greater influence on aquifer response to pumping near the coast than to pumping inland from the coast. Because much of the heavy pumping is along the coast, the lack of information of conditions off shore is unfortunate.

B. Middlesex County

Physical Characteristics

Of the various aquifers within the county three are of major importance. The rocks of the Newark group are the principal source of ground water in the northwestern part of the county. The Old Bridge and Farrington Sands, both members of the Raritan formation are the principal sources of water supply in the southeastern two-thirds of the county. The other aquifers are of relatively little importance either because of the limited area in which they are available or because they are not capable of yielding substantial supplies.

The Old Bridge Sand crops out or is exposed beneath permeable Pleistocene deposits in an irregular band that extends from the Raritan Bay near South Amboy to and probably beyond Jamesburg. The thickness range from 80 to 110 feet. The dip of the sand is variable but it averages approximately 40 to 45 feet per mile to the southeast. The water from the Old Bridge sand is excellent for most uses. Iron removal plants have been installed by a number of the larger users of water from this sand.

The Farrington sand occurs both north and south of the Raritan River and probably across the Arthur Kill on Staten Island. It crops out in a conspicuous band nearly a mile wide along the southeast edge of Farrington Lake where several sand pits give a good opportunity to examine it. The full thickness of the sand dips to the southeast at the rate of about 55 feet per mile. The uncontaminated water from the Farrington sand is exceptionally good for most purposes. The only feature of this water that is sometimes objectionable in its iron content.

The Triassic rocks in New Jersey belong to the Newark group which is divided into three formations: Stockton formation, the Lockatong formation and the Brunswick formation. All the sedimentary rocks of the Newark group dip to the northwest at angles of 5^{o} to 15^{o}. With the exception of the water that are contaminated by the intrusion of sea water, the water from the Newark group is more highly mineralized than any other groundwater obtained in Middlesex County. The water is high in calcium and magnesuim and the hardness is therefore high. Also there are high quantities of iron.

Analysis

There appears to be danger of salt-water intrusion into the Old Bridge Sand at two points. At the South Amboy Water Works where the Sand is exposed to salt water in the Raritan Bay and in the vicinity of Old Bridge where salt or brackish water in the South River comes in contact with its intake area. There is no widespread salt-water encroachment problem in this aquifer yet, however, the intensity and distribution pumping has been limited by the threat of such encroachment. In the vicinity of Parlin there are areas in which the Old Bridge sand has been contaminated by industrial wastes.

Widespread salt-water encroachment in the Farrington Sand Member has caused numerous wells to be abandoned. The three principal places where salt water has entered the Farrington Sand are near the confluence of the South River and the Washington Canal, about a mile downstream from the confluence of the Washington Canal and the Raritan River, and near the mouth of the Raritan River. The greatest advance of salt water has been in the area south of Parlin. If not restricted, the encroachment of salt water threatens to render a considerable part of this aquifer unfit for use in most of the area south of Parlin. There is overpumpage and the salt-water encroachment problem in the Runyon well field.

Industrial pollution around Runyon and pollution from land fills in the South Brunswick vicinity as well as isolated cases of septic system pollution are the threads of further degradation of water quality in the Middlesex County.

3. Central Shore

A. Ocean County

Physical Characteristics

Ground water in Ocean County is obtained principally from four artesian aquifer systems and a water-table aquifer. The artesian aquifers in ascending stratigraphic order are: the Raritan and Magothy Formations, the Englishtown Formation, the Wenonah Formation and Mount Laurel Sand, and the Kirkwood Formation.

The Raritan and Magothy Formations of Cretaceous age form an artesian aquifer system 600 to 2,000 feet thick. Well yield of 500 to 1,000 gpm (gallons per minute) can be expected, but yields as high as 1,850 gpm have been obtained. Recharge to the aquifers occurs from precipitation, mainly in the high level intake area from Trenton northeast to Metuchen in northern Middlesex Counties. Potable water in the aquifer system is soft (28 to 51 ppm hardness) and is generally high in iron content (0.66 to 3.2 ppm). Temperatures of 70° to 90°F make the water less desirable than shallow water for cooling purposes. In the southern part of the county, saline water is contained below 2,500 feet in depth in the Raritan and Magothy Formations, so wells approaching this depth may include saline water. The salt water-fresh water interface zone in the Raritan and Magothy Formations trends through the Island Beach State Park area.

The aquifer in the Englishtown Formation produces maximum well yields of less than 500 gpm, and the average is 260 gpm. Recharge to the formation occurs predominantly from vertical leakage down through the overlying younger formations in the topographic high areas of Monmouth and Camden Counties, 5 to 10 miles southeast of the Englishtown outcrop area. Water from the Englishtown Formation is soft to moderately hard (30 to 82 ppm hardness and the pH ranges from 7.5 to 8.3. The aquifer thins to the southeast and is absent in southern Ocean County.

The aquifer of the Wenonah Formation and Mount Laurel Sand yields small quantities of water to wells (less than 100 gpm) and is relatively undeveloped in northern Ocean County, however is capable of further development. The

Aquifers: U, undifferentiated water-table aquifer; K, aquifer in the Kirkwood Formation: V, aquifer in the Vincentown formation; W, aquifer in the Wenonah Formation and Mount Laurel Sand; E, aquifer in the Englishtown Formation; R, aquifer in the Raritan and Magothy Formations.

Area	Aquifer	Availability of ground water
1. Summer Coastal Resort	K	K, yields as much as 500 gpm. Used for public supply. Potential sea-water intrusion as water levels are below sea level. Summer pumpage, 5 mgd. R and contain saline water, E. W, and V are absent.
2. Undeveloped Pine Barrens	R,K.U	R, yields as much as 2,000 gpm possible. Saline water in southern part of area. K, well yields less than in Area 1. Water locally acidic and high in iron content U, yields as much as 1,000 gpm possible. Water may be high in iron content,

			acidic and odoriferous. E. W, and V are absent.
3.	Urban	R,E,W,K,U	R, same as in area 2. Pumpage 5 to 8 mgd. E, yields up to 500 gpm. Highly developed. Pumpage, e, mgd. Sea-water intrusion possible as water levels have declined as much as 90 feet. W, yields less than 100 gpm. Relatively undeveloped. Pumpage less than 1 mgd. K, yields up to several hundred gpm. U, same as in area w. V, absent.
4.	Rural	R,E.W,V,K,U	Small amounts pumped for domestic use. R,E,K, and W yields up to several hundred gpm are possible.

Table 3 - Summary of availability of ground water in Ocean County.

water is generally soft. It contains high iron concentrations locally. Downdip, the Wenonak Formation and Mount Laurel Sand becomes a confining bed.

The Kirkwood Formation in Ocean County has wells that yields as much as 1,225 gpm, but the average is about 420 gpm. Recharge to the Kirkwood Formation occurs in the topographic high areas of the inner Coastal Plain by vertical leakage from the overlying water-table aquifer. Water from the aquifer in the Kirkwood Formation is suitable for most uses but may require treatment for removal of iron. It is generally soft to moderately hard (2.9 to 105 ppm hardness) and generally low in dissolved solid content (4 to 180 ppm).

The water-table aquifer yields up to 600 gpm. In the sparsely settled Pine Barrens, 0.8 mgd per square mile theorectically can be withdrawn from the aquifer without depleting the storage. Water from the water-table aquifer has a low pH (4.4 to 6.7), high iron content (0.09 to 22 ppm), and an unpleasant odor. Near Barnegat Bay and on the barrier beach, the aquifer contains brackish water.

The Vincentown Formation which is tapped locally in the northwestern part of Ocean County for domestic supply could yield water in quantity to large - diameter wells near the outcrop area. Elsewhere, it offers little potential for further development.

The Manasquan Formation is generally considered an aquitard, but it yields up to 500 gpm to wells along the coast. This formation can be tapped further in Ocean County for small to moderate water supplies.

Analysis

Artesian aquifers of the Raritan and Magothy, Englishtown, Wenonah and Mount Laurel, and Kirkwood Formations and the water-table aquifer supply the present water needs of Ocean County. Of these, the Raritan and Magothy and the water-table aquifer are the largest and least utilized ground-water reservoirs in the county and are the most suitable for future large-scale development, however in the southern third of Ocean County, all aquifers in the Raritan and Magothy Formations probably contain water.

The aquifer in the Englishtown Formation is heavily pumped in northeastern Ocean County. In this area, water levels in wells have declined from above sea level to more than 75 feet below sea level since 1900, however, there is no evidence that the sea water has intruded the aquifer. The Kirkwood Formation is the most heavily pumped aquifers on the New Jersey coast south of Monmouth County. Since 1900, water levels in wells tapping this aquifer have declined to as much as 30 feet below sea level on Long Beach Island. In the Point Pleasant area where the Kirkwood crops out, salt water was found there.

The water-table aquifer is pumped heavily in the Toms River and Lakehurst areas. Further development of wells to maximum capacity will substantially diminish the flow of Toms River. Ground water pollution in this aquifer occurs from dumping of chemicals. The Pleasant Plains incident had caused closing of 150 domestic wells.

4. South Shore

A. Cape May County

Physical Characteristics

Three main aquifers yield fresh water in Cape May county; they are the unconfined Holly Beach water-bearing zone, the Cohansey Sand, and the Kirkwood Formation.

The Cohansey Sand is the most productive aquifer in Cape May County. It crops out along the Maurice River in Cumberland County and north of the Tuckahoe and Great Egg Harbor Rivers in Atlantic County. The principal high-level recharge area for the Cohansey Sand is not in the outcrop area but in the Belleplain area of Cape May County and is recharged by vertical leakage from the overlying Pleistocene sediments.

Water from wells tapping the Cohansey Sand have a low pH and are corrosive in the Woodbine area. In the lower peninsular area of Cape May County, the encroachment of salt water has impaired the quality of water in the aquifer.

The Kirkwood Formation represents a thick section of marine sand and clay beneath the Cohansey Sand. The formation contains two confined water-bearing zones. The top of the upper aquifer-Rio Grande water-bearing zone occurs from 260 feet below mean sea level in the northwestern part of the county to about 600 feet below mean sea level in the southeast at Wildwood, and the zone is on the average 50 feet thick.

The lower aquifer on Atlantic City "800-foot" sand is more widely used and has a greater potential than the upper aquifer. South of Wildwood it contains water of high chloride concentration--more than 250 parts per million-and relatively high dissolved solid content. Yields of between 500 to 800 gpm are common from the Atlantic City "800-foot" sand. The major source of recharge to the aquifers in the Kirkwood Formation is precipation in the outcrop area. The areal extent of the outcrop of the Kirkwood Formation extends for about 250 square miles from Gloucester to Monmouth Counties.

The aquifer most suitable for future development is the shallow unconfined Holly Beach water-bearing zone. It is recharged by direct percolation to the water table. The Holly Beach water-bearing zone crops out in Cape May County in an area of about 160 square miles, excluding the land area of the barrier bar from Ocean City to Wildwood and other tidal-march areas. In the lower peninsular area of Cape May County, there is no chance for a build-up of fresh-water head in the aquifer to prevent the salt-water interface from moving inland. The construction of wells near a lake or river where there is a known hydraulic connection with the aquifer affords the opportunity to develop a large-capacity supply by inducing infiltration of surface water. The water is slightly acidic and high in iron.

<u>Analysis</u>

The heavy development of the Cohansey Sand on the Cape May peninsula has lowered the water table below sea level in places. This has reversed the vertical and horizontal hydraulic gradients on the lower peninsula. Water is now moving to the centers of withdrawal at Rio Grande and Cape May Formation.

The withdrawals from the Atlantic City "800-foot" sand in Atlantic and Cape May Counties have reversed the hydraulic gradient and started a landward migration of salt water from the ocean. The deterioration of water quality in the Kirkwood Formation in the lower peninsular area of Cape May County is the result of salt-water encroachment caused by withdrawals from the aquifers.

The major problem dealing with future development of the Holly Beach water-bearing zone is the danger of salt-water encroachment. During severe subtropical or hurricane-type storms, salt sprey is driven appreciable distances inland in Cape May County. Salt-water flooding in areas of low elevation during these storms is the severe and devastating type of pollution. Other localized sources of pollution includes refuse disposal sites, septic tanks.

The Cape May Canal, which was constructed as a war-time measure during the 1940's, has lowered the water table about 12 feet in the center of the county and released several billion gallons of fresh water from groundwater storage. The canal created an island at the top of Cape May County and increased the danger of salt-water encroachment into the unconfined aquifer.

5. Delaware Bay

A. Cumberland County

Physical Characteristics

Almost all water supplies in Cumberland County are obtained from wells tapping shallow groundwater supplies. Most wells obtain water from the Cohansey-Kirkwood aquifer. Successively deeper aquifers occur in the lower part of the Kirkwood Formation, in the Piney Point Formation, in the Wenonah Formation and Mount Laurel Sand, and in the Potomac Group and Magothy and Raritan Formations. Each of these aquifers are separated by confining or semiconfining clay layers of varying thicknesses and permeabilities.

The Cohansey-Kirkwood aquifer has its recharge area in the uplands in the northern part of the county and its main discharge areas are in the eroded stream valleys and tidal march areas along Delaware Bay. The groundwater in the Cohansey-Kirkwood aquifer generally is low in dissolved solids, less than 100 mg/l, has a low pH (4.2 to 7.0), and is usually corrosive. The water locally contains objectionable concentrations of iron (up to 15 mg/l), and nitrate (up to 65 mg/l).

The second most important source of groundwater in Cumberland County is the lower Kirkwood aquifer. Most recharge to the lower Kirkwood aquifer probably comes from vertical leakage from the overlying Cohansey-Kirdwood aquifer in the western part of the county. The quality of water in this aquifer along the Maurice River and Delaware Bay indicates that the potential for salt-water intrusion is minimal under present rates in Cumberland County.

The Piney Point Formation, underlying the Kirkwood Formation, is a minor aquifer in Cumberland County.

The aquifer in the Wenonah Formation and Mount Laurel Sand offers a potential source of additional freshwater supplies in Northern Cumberland County. This aquifer is not presently utilized in the county, however, because adequate supplies are available from much shallower aquifers. Water quality in the northern part of the county, where water levels in the Wenonah-Mount Laurel aquifer are well above sea level, is very good as indicated by analysis of ground water in nearby Salem County. The water becomes more salty toward Delaware Bay.

Aquifers in the Potomac-Raritan-Magothy sequence contain saline water and are not currently utilized in Cumberland County.

Analysis

Groundwater supplies have been contaminated in a few areas in the county largely as a result of the leaching of agricultural fertilizers and the improper disposal of industrial wastes and domestic sewage. Practices and processes that lead to contamination of groundwater supplies are: poorly managed landfill and excavation operations; leakage of soluble sewage wastes from cesspools and septic tanks. Contamination problems have been reported in several shallow wells from several of these sources in Cumberland County.

Salt-water intrusion may occur seasonally in low-lying areas where shallow aquifers are hydraulically connected to Delaware Bay or other salt-water estuaries. Because of greater groundwater levels from pumpage in summer than in winter, water quality in many shallow wells near the tidal portions of Cohansey and Maurice River probably deteriorates seasonally. For such areas groundwater diversions must be carefully monitored to avoid damage to the water supply. Potential minor intrusion problems have occurred seasonally in centers of pumpage near the Greenwich and the Port Norris areas and along other tidal lowlands near Delaware Bay.

B. Salem County

Physical Characteristics

The important aquifers in the Salem County occur in the Potomac Group and Raritan and Magothy Formations, Wenonah Formation and Mount Laurel Sand, Vincentown Formation, Cohansey Sand, and Cape May Formation. Separating these aquifers are aquicludes composed of clayey materials.

The Potomac Group and Raritan and Magothy Formations contain the most productive aquifers in Salem County. They crop out in Salem County adjacent to the Delaware River in a 19-square mile triangular area that has a maximum width of 3 miles. These units underlie approximately 24 square miles of the Delaware River and extend southwesterly into the State of Delaware. In New Jersey, they dip to the southeast. The combined thickness of these formations in Salem County ranges from 200 feet in the outcrop area to about 1,000 feet or more downdip. Reported yields of wells tapping these aquifers range up to 360 gpm. The highest yields commonly occur where the system has direct hydraulic connection with the overlying Cape May Formation near the Delaware River. Chemical analysis indicate that most of the water from parts of the aquifer not contaminated by salt water is of good chemical quality.

The aquifer in the Wenonah Formation and Mount Laurel Sand is the second most highly used aquifer in Salem County and is an important source of water for future development. Ground-water recharge to this aquifer in Salem County, downdip from the outcrop, is derived mainly from vertical leakage from overlying aquifers. The combined breadth of outcrop for the two formations varies from 1 to 3 miles in Salem County, and their total thickness is not believed to exceed 120 feet. Reported yields of wells range up to 507 gpm. Water from this aquifer ranges from soft to very hard and is commonly high in iron. Salt-water intrusion, probably from the overlying Vincentown Formation in the vicinity of the City of Salem is indicated by chloride concentrations up to 396 ppm.

The aquifer in the Vincentown Formation is an important aquifer in part of Salem County. It is capable of supplying considerably more water than is now being pumped and hence is an important source for future groundwater development. Reported yields of wells tapping this aquifer range up to 270 gpm. The water is hard and is moderate to high in iron content. Salt-water intrusion is indicated by chloride concentrations of up to 2,850 ppm.

The Cohansey Sand, which underlies about 25 percent of Salem County is composed of highly permeable materials and hence is capable of transmitting large quantities of water. It is an important source for future groundwater development. It is rechared by precipitation on its outcrop area. The formation ranges in thickness from less than 1 foot near the western edge of its outcrop area to a known 82 feet and a possible 200 feet in the extreme eastern part of the county. Water in the aquifer is generally soft and slightly mineralized. However, iron and dissolved carbon dioxide are commonly present in objectionable quantities.

The Cape May Formation of Pleistocene age is an important aquifer in the Penns Grove-Deepwater area where it yields up to 1,500 gpm to Ranney collector wells. The Cape May Formation crops out adjacent to the Delaware River and its tributary streams and underlies about 85 square miles of Salem County. The formation is as much as 150 feet thick in the southwest and about 30 feet thick along streams in the interior of the county. Where Pleistocene deposits are not thick enough to function as an aquifer their chief hydrologic function is to absorb precepitation and transmit it to underlying formations.

Fine silt and clay of Holocene age occur in tidal flats and stream channels in Salem County. Along the Delaware River and its tributaries these relatively impermeable materials retard the movement of saline surface water into the water-bearing sands of the underlying materials.

Analysis

A decline in water levels in the aquifers of the Potomac, Raritan, and Magothy has resulted from heavy pumpage from this aquifer system. This pumpage has significantly modified the natural pattern of ground-water movement in the system. Whereas groundwater discharge was originally to the Delaware River and its tributory streams, it is now to centers of pumpage. Movement ~~of water~~ toward centers of pumpage has created the danger of salt-water encroachment into the aquifer from the Delaware River and its tributaries as well as from downdip areas where the aquifer already contains saline water. The occurence of saline water in the aquifer is indicated by chloride concentrations in the Salem Area and at Carneys Point. Several small areas of salt-water encroachment from the Delaware River have been developed in the Deepwater area. This does not represent a massive incursion of salt water into the aquifer but indicates that river water has access to the aquifer. The layer of silt and organic muck in the bed of the Delaware River and in the tidal parts of tributaries to the Delaware limits the rate at which salt water can enter an aquifer. Therefore, it is extremely important not to remove significant thickness of these protective materials.

Salt water may intrude the Cape May Formation along the Delaware River and along tidal reaches of its tributary streams if the fresh-water head in the aquifer is lowered sufficiently near places where the Delaware River and the Cape May Formation are hydraulically connected. Because water from the Cape May Formation recharges the older formations, water of poor quality entering the Cape May Formation could harm the underlying productive aquifer. Future ground-water withdrawals along the Delaware River should proceed with care to avert further expansion of those areas in which salt-water encroachment has taken place and to prevent establishment of new areas of encroachment.

6. Delaware River Water Front

A. Gloucester County

Physical Characteristics

There are four aquifers where moderate to large amounts of water can be pumped economically. They are: Raritan and Magothy Formations, the Cohansey Sand, and the Wenonah Formation and Mount Laurel Sand.

The Most important and productive aquifer is the Raritan and Magothy Formations. The aquifer yields about 75 percent of the groundwater used in the county. Wells yield up to 1,400 gpm and large capacity wells usually can be drilled almost anywhere in the county, however high chlorides may be present in the southeastern parts of the county.

The Raritan and Magothy Formations crop out in a belt 0.2 to 3.2 miles wide adjacent to the Delaware River and cover about 32 square miles of surface area in the county. The formations underlie the Delaware River and also crop out in Pennsylvania.

In the outcrop area two water-bearing zones are identified. The upper zone, usually artesian, includes the water-bearing beds in the upper 120 feet of the Raritan and Magothy Formations. The lower zone is always artesian in Gloucester County and is composed of the water-bearing beds in the lower 200 feet of the formations.

The Cohansey Sand is the second most important aquifer in the county and has the greatest potential for future development. The formation crops out of about 150 square miles in the sparsely populated southern half of the county and yields of 800 gpm are possible from wells less than 200 feet deep. The Cohansey Sand dips about 11 feet per mile and ranges in thickness from a few feet in the outcrop area to 130 feet at Newfield. Recharge to the Cohansey Sand is from precipitation on the outcrop area and groundwater movement is effected to some extent by the topography. From the high-level intake area near Gross Keys some groundwater moves south and discharges into the Great Egg Harbor River and some moves west and discharges into the Maurice River or its tributaries.

The most undesirable feature of the water in this formation is the iron content for which the water must be treated.

The Wenonah Formation and Mount Laurel Sand are capable of yielding 100 to 200 gpm to wells in the area between Pitman and Turnersville. The outcrop ranges in width from 0.3 to 3.0 miles and covers about 300 square miles. The combined thickness of the two formations in the county ranges from less than 65 to 95 feet.

The Wenonah Formation and Mount Laurel Sand is recharged mostly by leakage through the overlying formation. No single chemical analysis may be considered typical of water from these formations. Locally, two miles east of Wenonah, in the outcrop area well yields water that contains more than 100 mg/l each of chloride and nitrate.

Analysis

The quality of water in the Raritan and Magothy Formation is influenced by the quality of the Delaware River water. The Delaware River probably is as important a source of recharge as is precipitation on the outcrop area; therefore, the quality of the river water is of prime importance. During periods of low flow, river water of poor quality is more likely to recharge the aquifers. If preventative measures to maintain low-chloride concentrations in the river are not adequate, the groundwater supplies along the lower reaches of the Delaware River, will be the first affected. Also, the movement of groundwater is influenced by the areas of heavy industrial pumping on both sides of the Delaware River.

The Cohansey Sand in the county is almost undeveloped and is an extremely important potential source of large groundwater supplies, however, any large-scale pumping from the Cohansey Sand may decrease the flow of the main streams, such as Great Egg Harbor and Maurice River and in turn may allow increased upstream movement of saline water in the tidal reaches of the stream in Atlantic and and Cumberland Counties.

The high localized nitrate content in the Wenonah formation and Mount Laurel Sand indicated local pollution probable due to leached animal wastes or fertilizers. Pollution of this type is not uncommon in farming and rural areas.

B. Camden

Physical Characteristics

The physical characteristics of aquifers in Camden County are similar to Gloucester County aquifers.

Analysis

Areas of heavy pumping in or near the intake areas of the Raritan and Magothy aquifers reversed the normal flow pattern, so that induced recharge from bodies of surface water mainly from the Delaware River, now supplies much of the water drawn from wells. The water in the Delaware River upstream from Camden has generally been of satisfactory quality for recharging the aquifers, and along this reach of the river the quality of the groundwater has not been affected adversely by induced recharge. In some places downstream from Camden, the river water is more highly mineralized due partly to pollution by the disposal of wastes or by a combination of waste disposal and induced recharge from highly mineralized sources in Philadelphia and Camden, but mainly to the advance of salt water up the channel from the Atlantic Ocean. Induced recharge from the river in such places adversely affects the quality of the groundwater. Thus, for this aquifer the protection of aquifer recharge area, though important, is less important than protecting Delaware River water quality.

APPENDIX B
SOURCES

SOURCES

1. Anderson, Henry R. And Appel, Charles A., Special Report No. 29: Geology and Groundwater Resources of Ocean New Jersey Department of Conservation and Development, 1969.

2. Anderson, Henry R. "Geology and Groundwater Resources of the Rahway Area New Jersey". Special Report No. 27 USGS and New Jersey Department of Conservation and Economic Development, 1968.

3. Appel, Charles A. "Salt-Water Encroachment Into Aquifers of the Raritan Formation in the Sayerville Area, Middlesex County New Jersey"; USGS and New Jersey Department of Conservation and Economic Development, 1962.

4. Baldwin, Helen L. "A Primer on Groundwater" United States Government Printing Office, Washington, 1963.

5. Barksdale, Henry C. And others; "The Groundwater Supplies of Middlesex County New Jersey", USGS and State Water Policy Commission, 1943.

6. Barksdale, Henry C. "Groundwater Resources in the Tri-State Region adjacent to the Lower Delaware River" USGS and States of New Jersey, Pennsylvania, and Delaware, 1958.

7. Caputo, Darryl; Hochman, Michael; Hougen, Stewart;

"Ecological Planning: Water Resources Study on the Assunpink Water", M.S. Thesis, University of Pennsylvania, 1973.

8. De Camp, Stephen - Telephone Communication, August 20, 1976, Middlesex County Planning Board.

9. Epstein Sue, "Monmouth To Open Water Study" The Star-Ledger, July 20, 1976.

10. Gill, Harold E. "Groundwater Resources of Cape May County, New Jersey Department of Conservation and Economic Development Special Report 18, 1962.

11. Goldman, Evans, Jenner, Lawrence III., Repaupo Creek Watershed; Gloucester County, New Jersey: An Environmental Planning Study". Master's Thesis University of Pennsylvania, 1974.

12. Hard, Hilton; "Water Resources and Geology of Gloucester County, New Jersey" USGS and New Jersey Department of Conservation and Economic Development, 1969.

13. H. A. Swenson and H. L. Baldwin; "A Primer on Water Quality" United States Government Printing Office, Washington, 1965.

14. Jablonski, Leo A., Special Report No. 23: Groundwater Resources of Monmouth County, New Jersey; Trenton,

Department of Conservation and Economic Development, 1968.

15. Johnson, Meredith E. and Wilbur, Charles P., The Geology of New Jersey, Trenton, Department of Conservation and Development, New Jersey, 1940.

16. Lazier, Jim, Telephone Communication, August 11, 1976.

17. McCall, John E., Groundwater in New Jersey, Trenton, USGS Unpublished paper.

18. Nichols, William D. "Groundwater Resources of Essex County New Jersey" Special Report No. 28, USGS and New Jersey Department of Conservation and Economic Development, 1968.

19. Pollock, Steve; Telephone communication August 20, 1976, Ocean County Planning Board.

20. Pettyjohn, Wayne A., "Water Quality In A Stressed Environment" Readings in Environmental Hydrology, Burgess Publishing, ~~Minneapolis~~, 1972.

21. Rooney, James G. "Groundwater Resources, Cumberland County", New Jersey Special Report No. 34, USGS and DEP 1971.

22. Rosenau, Lang, Hilton, Rooney; "Geology and Groundwater

Resources of Salem County, New Jersey", Special Report No. 33, USGS and State of New Jersey Department of Conservation and Economic Development 1969.

23. Rutherford, Dave; Telephone Communication August 11, 1976.

24. Widmer, Kemble to Kinsey, David, "Conversation with Mr. Rivkin - Recharge Areas in the Coastal Zone", 7 January 1976.