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GROUND WATER COMPUTATIONS IN NEW JERSEY, U.S.A.

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In rural areas the 100-year flood of smaller watersheds has a strong dependence on the permeability of the geologic subsurface of the watershed and on the point rainfall intensity.
Based on 70 000 well record files in the state of New Jersey, U.S.A. the ground water availability in the rock formations have been estimated.

GROUND WATER STORAGE CAPACITY IN GENERAL

Ground water is an important source of water supply throughout the world and it occurs in permeable geologic formations known as aquifers (water bearing formations), that is, formations having structures that permit appreciable amounts of water to move through them under general field conditions.

From our view point, that portion of a rock or soil not occupied by solid mineral matter may be occupied by ground water. These spaces are known as voids, interstices, pores, or pore spaces and they are characterized by their size, shape, irregularity, and distribution. The original or primary voids had been created by geologic processes governing the origin of the geologic formation and are found in sedimentary and igneous rocks. After the rocks were formed, secondary voids developed as joints, fractures, faults, solution openings, and openings formed by plants and animals or pores caused by man's activity – earth works (excavation and backfill) and mining operations. Capillary and subcapillary voids will be not treated here because their influence on water storage capacity is less significant.

It is estimated that 97.54 % of all fresh water on the earth is ground water and half of this amount is available at a depth of less than 800 m under the surface (Doxiadis 1967).

Ground water constitutes one portion of the earth's water circulatory system, also called the hydrologic cycle. Water-bearing formations (aquifers) of the earth's crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations from the earth's surface or from bodies of surface water, after which it travels slowly for varying distances until it returns to the surface by the action of natural flow, pressure, plants, or man.

Water within the ground moves downward through the unsaturated zone under the action of gravity, whereas in the saturated zone it moves in a direction determined by the surrounding hydraulic situation. Ground water discharge occurs either by gravitation, under pressure (artesian well, etc.) or by pumping from wells. The latter constitutes the major artificial discharge of subsurface water.

Shortages of ground water in areas of excessive draft emphasize the importance of correct estimates and proper development, regulation, and protection of supplies in order to insure the continued availability of this key natural resource. Ground water usage has increased at an accelerating rate in recent years, and indications are that the trend will continue. For example, according to the U.S. Geological Survey, 2.27 million m^3/day ground water was registered in New Jersey, U.SA. in 1965 (Todd 1972). This quantity was only about 10 % of the total fresh water use but shows a 24 % increase for the past decade.

Before discussing the ground water storage estimate in New Jersey, it would be of some merit to review the hydrogeologic, rainfall and storm conditions in East Czechoslovakia and New Jersey governing the peak and low surface flows.

Research conducted by the author in Czechoslovakia, West Germany and New Jersey in the 1950's, 1960's and 1970's confirmed the principle that in rural areas the 100-yr peak runoff smaller watersheds has up to a 90-95 % dependence on the permeability of the geologic subsurface of the watershed and, in addition, on point rainfall intensity and configuration of the terrain. The vegetative cover and the form (concentration) of the watershed are additional factors (Halasi-Kun 1972). Local configuration of the terrain, elevation above sea level, and average yearly rainfall values of the drainage basin at moderate climatic conditions had far less influence on the 100-yr flood flow.

The developed formula of peak runoff has the following general pattern:

$$Q = C \cdot A^{-e}$$

$$\text{or } Q = (P_1 \cdot P_2) \cdot (i_1 \cdot i_2) \cdot A^{-e} \cdot (c_v \cdot c_c'),$$

where

Q = peak runoff in m^3/sec. km^2

C = coefficient which varies from 0.5 to 147 according the geologic and climatologic conditions (coefficients for vegetative cover and concentration of the watershed not included)

A = area of watershed in km^2

e = configuration of terrain (geographic region and slope characteristic): 0.32 for plains up to 0.5 for Alpine type mountains

P_1 = permeability factor of the soil and of the geologic subsurface with a value from 1.0 to 18.5

P_2 ≡ urbanization factor, from 1.0 to 14.0, in accordance with the impervious land-use and permeability of the geologic subsurface

i_1 = 24-hr point rainfall intensity, from 0.5 to 2.0, (0.5 for 35 mm/day; 1.0 for 125 mm/day; 2.0 for 250 mm/day)

i_2 ≡ storm characteristic, from 1.0 to 4.1, (depending on the size and pattern of the extreme storms and on the wind velocity)

c_v ≡ coefficient of vegetative cover, from 0.95 to 1.05, (from 40 % to 70 % of watershed area covered by forest)

c_c = concentration coefficient, from 0.90 to 1.05, (0.90 for elongated shape or at least 1:5; 0.95 for horseshoe-shaped and 1.05 for fan-shaped watersheds)

The further importance of these basic formulas is that they were established according to the geologic subsurface and the point rainfall intensity of Central Europe for watersheds less than 310 km^2 (Halasi-Kun 1973a). Finally, the basic formula is applicable not only for New Jersey, U.S.A. conditions (Halasi-Kun 1973b), but its validity was confirmed also for Australia (McMahon 1969).

GROUND WATER ESTIMATE IN NEW JERSEY, U.S.A.

It is obvious that the rate of surface runoff must be related in an inverse way to the permeability of the geologic subsurface of the watershed; and the quality and quantity of ground water storage is directly dependent on these conditions. Based on over 70 000 well record files of domestic and industrial wells throughout the State of New Jersey (area 20 295 km^2) for a period from 1947 to 1972, the ground water availability in the rock formations from Precambrian through Triassic in age and in unconsolidated sediments from the Cretaceous to the present, can be estimated. Comparison of large statistical samples of well records in rock formations to a depth of as much as 500 m has provided a means of estimating the ground water potential of areas underlain by specific rock types (Miller 1973, Widmer 1966, Rhodehammel 1970, Barksdale 1958 and Kasabach 1966). Several of these estimates of ground water availability have been tested against the experience in areas of suburban development during times of drought which occurred from 1961 to 1966. There is sufficient consistency in the results so that underlying rock and sediment types may be determined from well data where they are otherwise concealed by soil and overburden.

The areal distribution of ground water in New Jersey may be described in accordance with the physiographic provinces of the Garden State (see also Table 1):

(1) The Appalachian Highland and Valley Province in the North is the poorest region for ground water supply. The Paleozoic igneous rocks yield about 63 mm/year, and even in cases where these rocks are extremely weathered, they do not give more than 150 mm/year. In the valleys in the area of Kittatinny Limestone, the yield varies from 125 to 225 mm/year according to local conditions (calcium and magnesium content of the limestones, stratified drift, etc.). The Paleozoic Shales' capacity is below 47 mm/year.

(2) The Piedmont Province, comprising the central part of the State, (confined from the North by Ramapo Valley – Bernardsville – Clinton – Holland and from the South by Staten Island – New Brunswick N. – Trenton) is distinguished by the higher yielding Mesozoic Triassic Brunswick Formation (175 mm/year) and by the lower yielding Basalt and Diabase including the Triassic Stockton Formations in Hunterdon Country and the silty Brunswick Sandstones in Bergen, Essex and Union Counties (87-125 mm/year). An extremely low yield of less than 47 mm/year is characteristic for the Lockatong and argillaceous Brunswick Formations in Hunterdon, Mercer and Middlesex Counties. Many drilled wells of moderate depth are supplied from joints in the crystalline rocks and in fault zones. Many shallow dug wells are supplied from surface deposits or from the upper decomposed part of the bedrock. Some wells in Triassic Sandstones yield rather large supplies. Special attention should be given to the geological "Lake Passaic" in the Upper Passaic Valley where large diluvial deposits of gravel 30-60 m deep topped by heavy clayey layers are potential ground water storage areas.

(3) In the Atlantic Coastal Plain Province the water is derived in rather large quantities from Mesozoic Cretaceous (Magothy-Raritan) Formations, Tertiary Neogene Sands and Quaternary deposits, chiefly sand and gravel interbedded with clay. Large supplies are obtained from Tertiary Cohansey Sands near the Atlantic Coast. The aquifers yield 250-425 mm/year. The large

area of Pine Barrens including Wharton Tracts yield 305 mm/year, also for a longer period (Rhodehammel 1970).

This general description of the three physiographic provinces has no bearing

SEDIMENTARY ROCKS

Cenozoic

Quaternary—Recent deposits of the last 10,000 years are chiefly beach sands forming Sandy Hook and the offshore bars. Pleistocene or ice age starting 1,000,000 years ago. Mineral production—peat moss, sand, and gravel.

Tertiary—Starting 70,000,000 years ago. Unconsolidated sands, gravels, and clays. Forms the outer Coastal Plain. Marked by three different periods of invasion by sea, separated by erosional periods of dry land. Mineral production—brick and terracotta clays; glass sands; ilmenite (titanium ore).

Mesozoic

Cretaceous—Starting 125,000,000 years ago. Unconsolidated sands, clays, and greensand marls Forms the inner Coastal Plain. Appalachian Province uplifted and coast depressed; fast moving rivers deposited sediments in marine environment. Mineral production—fireclay, brick clay, greensand marls.

Triassic—Starting 200,000,000 years ago. Shales, argillites, sandstone, and some conglomerates. Forms Piedmont Plain. Appalachian Mts. uplifted and long thin depressed basins formed between ridges; fast moving rivers deposited sediments in these basins. Mineral production—Stockton sandstone (brownstone) for building stone; negligible amounts of copper found in some shales.

Paleozoic

Devonian—Starting 330,000,000 years ago. Sediments occur in two areas, 1) fossiliferous, calcareous shales and limestones in Appalachian Plateau, 2) sandy shales, sandstones, and conglomerates in valley south of Greenwood Lake in Highlands. No significant mineral production.

Silurian—Starting 360,000,000 years ago. Coarse conglomerates, sandstone, shale and, limestone. Occur to the southeast of Devonian sediments. From early Devonian, when sea receded to early Upper Silurian, N.J. was dry land.In late Silurian, the sea receded for a very short period and then re-invaded land. No significant mineral production.

Ordovician—Starting 420,000,000 years ago. Limestone, shales, and slates. Found in the Highlands and Appalachian Plateau. Three different invasions of land by sea, with erosional periods of dry land in between. Mineral production—cement rock and slate.

Cambrian—Starting 500,000,000 years ago. Quartzite followed by limestone. Found in the Highlands and Appalachian Plateau. During first and last parts of Cambrian time N.J. was covered by seas, while in Middle Cambrian time it was dry land

Precambrian—Franklin limestone—more than 500,000,000 years old. Typically a white crystalline limestone. Found in a narrow belt and a few isolated masses in the Highlands. Mineral production—zinc deposits at Franklin and Ogdensburg; limestone for flux and cement rock.

IGNEOUS ROCKS

Triassic—Diabase and Basalt—The same basic rock formed from cooling molten material. Differ in texture. Diabase is coarse grained due to slow cooling beneath the surface while basalt is fine grained due to quick cooling of lava at the surface. Diabase forms the Palisades and its extensions to the south in the Princeton area. Basalt forms the Watchung Mts. and the two small masses at New Germantown and Sand Brook. Diabase and basalt are extensively quarried for concrete, road metal, and railroad ballast.

Precambrian—Gneiss and Granite. Granite is a coarse grained igneous rock characterized by predominant alkali feldspar and quartz. Gneiss is a crystalline rock with a secondary rough foliation developed as a result of pressure on the solidified rock; bands or lenses in gneisses are commonly unlike. Metamorphic rocks are included in this zone, some of them having been derived from sediments. These rocks form "The Highlands of New Jersey". Mineral production—magnetite (iron ore), crushed stone and prospects for uranium, monazite, and rare earths.

Table 1.

Geologic formations in New Jersey.

on exceptional high capacity wells and the characteristic yields are given for the periods of drought. Further significance of these well records is that they include the unsuccessful wells attempting to get amounts of water in excess of 47 mm/year. Approximately 15 % of the total recorded number of wells – especially in Northern New Jersey – fell in this category and give valuable information about the ground water conditions of the different geological formations. Many of these wells in Northern New Jersey have been completed in the thick Pleistocene outwash deposits and most of the rock wells also have relatively thick covers of Pleistocene sands, gravels, and tills. The Pleistocene wells that have been unsuccessful (107 wells) have been drilled in thick tills, or silt-clogged outwash. Rock wells were unsuccessful (112 wells) because of a thick till cover over the underlying rock (Widmer 1966).

Finally, the general location of the watershed has a decisive influence on the ground water availability. In the head water area the ground water quantity has a tendency to decrease due to the adjacent lower lying regions. In the lower courses area the ground water capacity may be increased by the additional ground water flowing from the abutting higher watertable area.

The gathered statistical data on ground water availability in New Jersey is based also on pumping tests and records of the wells, and their figures can be accepted on the assumption of an average yearly rainfall of 1125 mm – which value can drop for two consecutive years of drought even to a yearly 850 mm. The ground water in the northern half (rock country) of the area studied is available only to a depth of 180 m below the surface. Boring tests proved that below that level there is a very marked decrease in fractures and fissures from which water can be obtained. There is also evidence, of course, that certain fracture zones may give abundant water at great depth, but these fractures are those such as the Triassic border fault or others that have been mapped for years. In the coastal half (coastal plains) of this examined region, the limit according to the aquifer layers (water containing layers) is from 190 to 1000 m (from West to East) below sea level (Barksdale 1958).

It must be stressed that along fracture zones and faults, there is always a possibility of more ground water due to a greater permeability in the formations, even for longer distances. The same principle applies for border lines delineating the different geologic formations since the contact of these formations is never uniform and in most cases has a greater percentage of voids than the adjacent area. Consequently, this permits easier mining or outcrop of ground water. Generally, these zones include the regions of springs and wells of greater capacity. Therefore, the boundary lines in Fig. 1 (indicating the various main hydrogeologic regions) are also the zones of greater ground water potential, especially in water poor regions. Similar attention should be given to

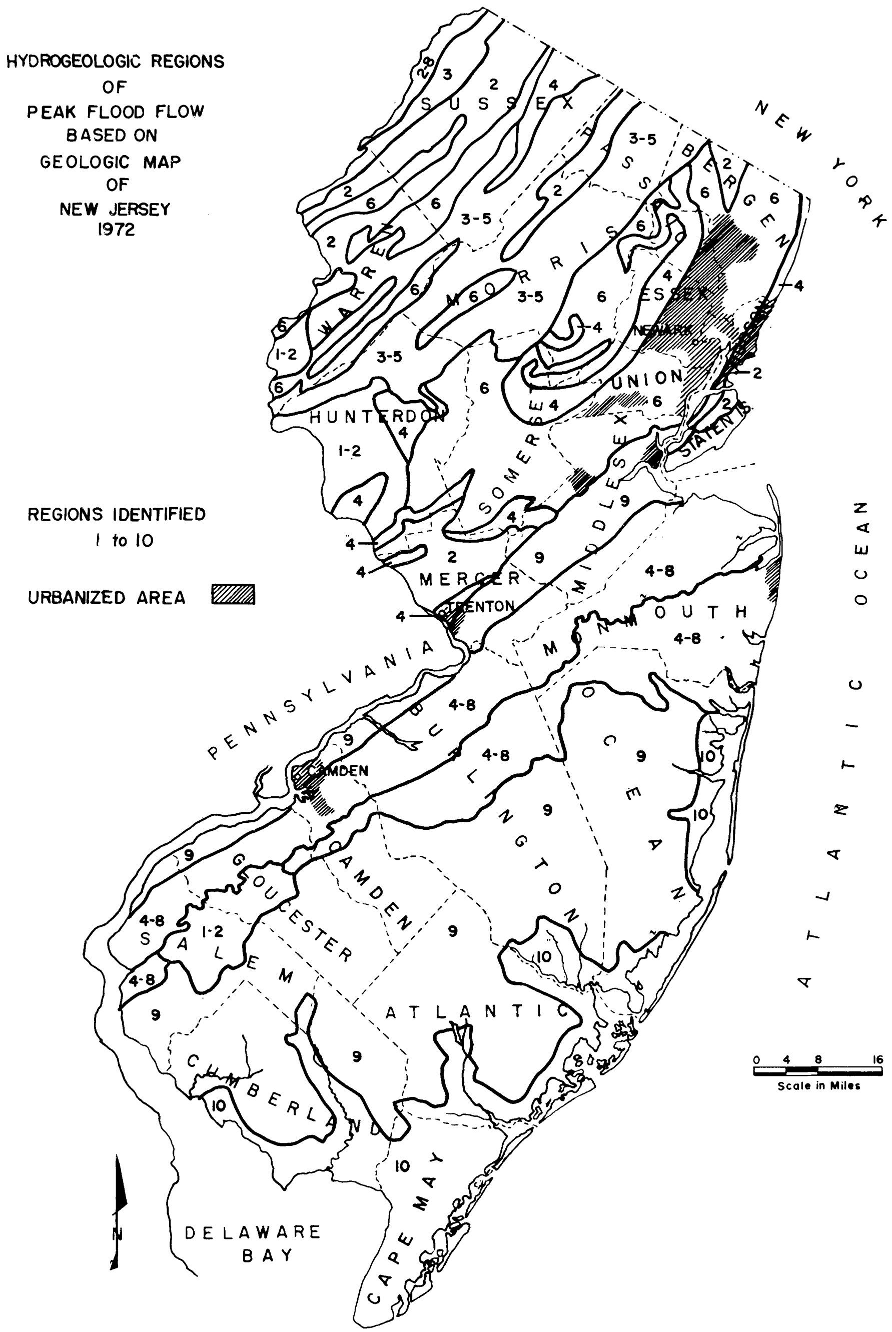
HYDROGEOLOGIC REGIONS
OF
PEAK FLOOD FLOW
BASED ON
GEOLOGIC MAP
OF
NEW JERSEY
1972
REGIONS IDENTIFIED
1 to 10
URBANIZED AREA ▨
NEW YORK
PENNSYLVANIA
ATLANTIC OCEAN
DELAWARE BAY
SUSSEX
PASSAIC
BERGEN
WARREN
MORRIS
ESSEX
NEWARK
HUDSON
UNION
STATEN IS.
HUNTERDON
SOMERSET
MIDDLESEX
MERCER
TRENTON
MONMOUTH
BURLINGTON
OCEAN
CAMDEN
GLOUCESTER
SALEM
CUMBERLAND
ATLANTIC
CAPE MAY
0 4 8 16
Scale in Miles
N

Fig. 1.

the limestone areas with numerous secondary openings and caverns, as is the case along the Kittatinny formations in Northwestern New Jersey.

The evapotranspiration and interception average 450-560 mm yearly, and average runoff is up to 550 mm from the annual precipitation. The ground water availability indicator has a value from 0 to 450 mm yearly, depending on the permeability and storage capacity of the geological formations (Halasi-Kun 1971).

Despite the fact that the estimate of the regional availability is complicated by factors such as recharge or transmissability from adjacent areas, there is clear evidence of correlation of permeability of geological formations with surface peak runoff and ground water availability. The comparison can be based only on average values of permeability because they are measured under difficult conditions and in various geological formations which are commensurate to formations used in establishing of runoff formula coefficients and ground water availability indicators (Table 2). It must be pointed out that the various formations are also, in general, already mixed or interwoven even in smaller drainage areas. The uneven surface weathering, artificial impervious surface due to urbanization, the disintegrated underlying rock formations at various depths and the possible present faults add to the difficulty of establishing a practical average value of permeability, ground water availability or surface runoff even for a smaller watershed.

The minimum ground water availability in mm/year given in Table 2 is based on records of lengthy periods of drought such as the 1961-1966 drought of New Jersey. For years with average rainfall, these values may be increased by 50 %. On the other hand, the available quantity of ground water for practical planning purposes can be augmented further by an additional 50 %, to a total of 200 %, assuming that the ground water will be "mined" (taking out more than the natural supply). This type of planning can lead to the danger of exhausting the stored ground water quantity, lowering the ground water table, and causing additional problems.

CONCLUSION

The various studies about surface flow showed that the geological subsurface has an effect only on smaller watersheds with an area of 310 km^2 or less. By increasing the watershed area, the flow curves of the various hydrogeologic regions are convergent. The "geologic" character of the runoff coefficient starts to "fade away" and for a watershed of over 340 km^2 the computations already

Table 2.

Ground water availability in various hydrogeologic regions of New Jersey, U.S.A. and their average permeability.

Hydrogeologic Regions: (formations)	*Ground Water Availability* in mm/year	*Average Permeability* in millidarcys:*
(1) Kaolinite, Clay including argillaceous Triassic or Tertiary Paleocene Flysch	17-25	1
(2) Paleozoic Shales, Schist and Mesozoic Marl	less than 47	1-1.9[2]
(3) Igneous Rocks (except Basalt, Diabase), Sandstones, Mesozoic Triassic Stockton Form	63	2.5[2]
(4) Dolomite, Basalt and Tertiary Marl	87-125	4[2]
(5) Weathered Igneous Rocks, Limestone, Tuff	150	?
(6) Mesozoic Triassic Brunswick Formations	175	6[2]
(7) Mesozoic Cretaceous Clayey Sands, Tertiary Eocene Clayey Sands	250	?
(8) Tertiary Miocene Sands and Quaternary Moraines	300	10[2]-14[2]
(9) Tertiary Neocene Sands, Mesozoic Cretaceous Magothy-Raritan Formations, Quaternary River Drift	350	10[2]-14[2]
(10) Quaternary Beach Sands (Cape May Formations)	425	18.2[2]

* 1 millimeinzer = 18.2 millidarcys

Values are based on over 70 000 well record files of domestic and industrial wells of the State of New Jersey from the period of 1947-1972. Further information, especially for regions (2), (3), (6), (7) and (9), is in references already mentioned: articles and books of Miller, J.; Widmer, K.; Rhodehammel, E. C.; Barksdale, H. C.; Kasabach, H. The form of data on average permeability makes easy comparison with permeability factors (geological coefficient) of the peak runoff formula. (See also: Davis, St. N., DeWiest, R. J. M. *Hydrogeology,* New York-London-Sydney: J. Wiley & Sons, 1966 and Linsey, R. K. Jr., Kohler, M. A., Paulhus, J. L. H., *Hydrology for Engineers,* New York-Toronto-London: McGraw-Hill, 1958.)

show more than ± 20 % error compared with the observed values of the same area. Therefore, the use of formulas for greater drainage basins based on geologic conditions is not recommended because other factors affect the flood flow, and the influence of geological factors is less important or becomes inferior in value. Even more confined in area is the ground water availability estimate where the practical upper limit in New Jersey may be less than 200 km^2, depending on the surface conditions and on the complexity of the subsurface rock formations. The limit can be extended only for calculations of greater area with uniform geological subsurface.

Note that runoff – the water that appears in streams – also includes ground water discharge as well. This means that ground water is not something to which we can look as an entirely new source of water once we have fully exploited the streams, but something that is part of the same supply and must be computed and utilized accordingly.

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