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DEVELOPMENT OF NITRATE DILUTION MODEL FOR LAND USE PLANNING IN THE STATE OF NEW JERSEY

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Development of a Nitrate Dilution Model for Land-Use Planning in the State of New Jersey

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1. INTRODUCTION

Traditional tools for evaluating the suitability of a development site for onsite wastewater disposal from conventional septic systems focus on the ability of the surface soils and underlying geologic formations to absorb and transmit septic effluent. These evaluations (e.g., percolation tests) are frequently accurate in determining the ability of the land to support individual septic systems with respect to the filtering and drainage ability of surface and subsurface soils. However, such tests do nothing to evaluate the ability of the environment to dilute and transport contaminants safely out of the watershed. Thus, groundwater degradation may occur in areas having a high density of approved, properly functioning septic tank systems; this may be compounded by additional contaminants introduced by intensive agricultural use of the land.

The objective of this report is to develop and apply a nitrate dilution model which provides guidelines for housing densities which will prevent groundwater degradation in non-sewered areas of New Jersey. This report only considers groundwater degradation from septic tank effluent.

Septic tank contamination is characterized by high concentrations of nitrates, bacteria, and in some cases, significant quantities of organic compounds (Canter and Knox, 1984; Hughes, Pike, and Porter, 1985; Caroline County Comprehensive Plan, 1987). Since nitrate (NO_3^-) is a highly mobile and stable anion in shallow aquifer conditions, its presence is often monitored as a gauge (indicator) of overall groundwater quality (Bachman, 1987). Regulatory programs designed to prevent pollution from septic tank effluent therefore frequently use nitrate concentrations in groundwater as the indicator if compliance.

Some portion of shallow groundwater usually discharges to nearby streams and maintains their flow during times of negligible precipitation. This discharge is termed base flow. However, water quality degradation in this shallow groundwater will eventually manifest itself in the stream, because of the relationship between base flow and stream flow. High nitrate concentrations in groundwater can cause eutrophication of surface water. At concentrations in excess of 45 milligrams per liter (mg/l), nitrate can be fatally toxic to infants, producing methemoglobinemia (blue baby syndrome) (Caroline County Comprehensive Plan, 1987; U.S. Environmental Protection Agency, 1977). In the context of all water quality standards discussed in this report, the term “nitrate” refers to nitrate-nitrogen (NO_3-N).

Because of the potential health impacts of excess nitrate in drinking water, the U.S. Environmental Protection Agency has set an upper limit of 10 mg/l for nitrate in groundwater for domestic uses. This value is based in part on the economics of removing nitrates in public water supply treatment systems. To protect natural ecosystems and water supplies drawn from individual wells from contamination by septic system pollution, lower limits on nitrates may be appropriate. For example, the New Jersey Pinelands Commission has established a stringent limit of 2mg/l for nitrate as a protective measure for maintaining high water quality in the fragile environment of the Pinelands.

Nitrogen compounds introduced into the ground as septic wastes are attenuated by two processes: chemical renovation, and physical dilution with transport out to watershed. The capacity of a soil to renovate nitrate-containing effluent is dependent on the dissolved oxygen content, pH, anion/cation adsorption capacity, and organic carbon content of the soil. These factors combine to create the right physical environment for the chemical adsorption of nitrogen compounds and create a favorable environment to support denitrifying bacteria (Freeze and Cherry, 1979).

The mineral composition of a soil is a key factor in determining its diluting and renovating capacity. Soils rich in clay minerals are generally good chemical renovators but can be poor transporters. In these soils, the physical transport and dilution of nitrates is relatively slow. However, in the permeable sandy soils typical of New Jersey's Atlantic Coastal Plain, nitrate derive from septic effluent will pass rapidly through the unsaturated subsoil (vadose zone) into the saturated zone below the water table with little natural renovation.

The actual capacity of soils to renovate nitrate derived from septic tank effluent is very much debated; for example, one study found that there is essentially no renovation of nitrates below a depth of about three feet (Canter and Knox, 1984), while another study concluded that the capacity of a column of soil to renovate nitrates is significantly diminished after several years (Hill, 1972).

When the nitrate renovation capacity of a soil is low or non-existent, then the primary mechanism for the attenuation of nitrate (and other contaminants) is dilution of nitrate-containing effluent by infiltrating rainwater. Some dilution of septic effluent by groundwater may occur, depending on individual site conditions. However, because groundwater flow tends to be non-turbulent or may be restricted by low-permeability zones in the soil, the amount of mixing may be highly variable. This assumption is based on several studies of nitrate plume migration and appears to be valid for soils and sediments similar to many of those found in New Jersey (Nieswand and Pizor, 1974; Ragone and others, 1987). The environment's dilution capability is then a function of the quantity of rainwater or other precipitation that infiltrates into the ground and the natural (background) concentrations of nitrates in the precipitation.

The amount of infiltration, or water that actually reaches the saturated zone, that is derived from precipitation is dependent on several factors. These factors include the amount of precipitation, the permeability and slope of the surfical coils, the moisture content of these soils, and the amount of evaporation and transportation by plants. Infiltration is commonly calculated as a percentage of the average annual precipitation for a particular area with similar hydrogeologic characteristics.

In addition to constraints imposed by the natural environment, the final nitrate concentration of groundwater which has assimilated septic effluent depends on the quantity of effluent introduced to the surface formations and the concentration of nitrate in the effluent. Related variables that affect these nitrate concentrations are housing density, the number of persons in each household, and the quantity of septic effluent produced by each person, which may be assumed to roughly equal individual daily water usage (Wehramm, 1983).

As stated above, the objective of this study was to develop and apply a nitrate dilution model to provide guidelines for supportable housing densities in watershed or other areas of interest throughout New Jersey. Development of a suitable model was limited to examining and refining various models that have been used in the past. Application of the model, which is intended to be used on a regional basis as a planning tool, involved assembling and evaluating the suitability and accuracy of disparate data on hydrogeologic conditions throughout the State, nitrate contamination from septic systems, and water quality in each of the watersheds located in New Jersey. This process is discussed in Sections 2, 3, and 4 of the report.

The nitrate dilution model developed for the New Jersey Office Of State Planning is discussed in Section 5 of this report. The model incorporates factors resulting from disposal of residential wastewater through conventional septic systems that affect nitrate concentrations.

2. EVALUATION OF AVAILABLE DILUTION MODELS

Several nitrate dilution models have been developed by various workers to simulate the effect of septic system effluent on groundwater and surface water quality. The nitrate models which were examined for this study are mass-balance models. Mass-balance models determine the concentration of a substance (in this case, nitrate) leaving a certain physical system by first calculating the product of the influent column of water and concentration of that substance coming into the system from all sources. This product is then divided by the volume of water leaving the system to yield the exiting concentration of the substance of interest. The models differ in the choice of parameters that are used in the equation; some more closely simulate the natural processes at work in the field, such as dilution by resident groundwater. The following paragraphs present a brief discussion of the models evaluated for this study.

A dilution model was developed to estimate the impacts of septic systems on groundwater in the New Jersey Pine Barrens (Trela and Douglas, 1978). In this model, the nitrate concentration in septic effluent, and the volumes of septic effluent and infiltrating rainfall are the input parameters. The Trela-Douglas model does not consider dilution by groundwater already present beneath a site, nor does it consider possible attenuation of nitrate in the effluent by soil interaction. The rationale for this is based on the typical characteristics of groundwater flow conditions; that is, since groundwater flow is usually laminar (non-turbulent), the opportunity for complete mixing of shallow groundwater with effluent or infiltration is very limited. Site-specific anomalies such as clay lenses may inhibit mixing and thus are inappropriate for consideration on a regional basis. Also, infiltration tends to displace groundwater downward, further decreasing the degree of mixing between the groundwater and incoming effluent (Trela and Douglas, 1978). Regulatory agencies in New Jersey also do not consider the dilution capability of groundwater when determining the capability of onsite disposal systems to meet State water-quality goals. This policy is rooted in the potential site-to-site variability of pertinent hydrogeologic conditions, which can make estimates of regional groundwater dilution capability tenuous at best. Since the essence of the Trela-Douglas model supports these regulatory programs, this model was selected for use in this study.

A later adaptation of the Trela- Douglas model (Pizor, Nieswand, and Hordon, 1983) included an additional factor to allow simulation of soil renovation of the septic effluent, as well as factors for infiltration and septic effluent volume and nitrate concentration. This model also did not consider dilution by groundwater. The inclusion of soil renovation factors in the model intuitively improves its realism by simulating the natural system, but currently there is no documentation to support the choice of value for any given soil. Based on this lack of supportable data, and evidence that soil renovation effectiveness decreases over time (Starr and Sawhney, 1980), this model also was not considered.

An existing algorithm known as the Water and Land Resource Analysis System (WALRAS) was used to simulate the movement of nitrate and pesticides in shallow water in the pine barrens area of Long Island (Pacenka and others, 1981). This model requires a fairly high degree of data input, and was therefore considered to be inappropriate for use on a state-wide basis in New Jersey because of the overall lack of site-specific data for all areas of the State.

Various nitrate dilution models were reviewed for use in Greenwich Township, Warren County, New Jersey in a report by Greene Environmental Consultants (1986). This review contained a discussion of the mechanics of several models, including those mentioned above, as well as a similar model developed for Greenwich Township. The report did not document the latter model, but only discussed the choice of input parameters and the lot sizes recommended by the model output. Because the model was not completely described, and because it applied specifically to a unique study area, it was considered to be too limited for consideration in this project.

A nitrate dilution model also was developed by Wehrmann (1983) for a study area in Illinois. This model included groundwater as part of the dilution process. However, since the Wehrmann model considers groundwater dilution, it does not support current State policies on water quality protection (NJDEP- Division of Water Resources, 1988). Therefore, the Wehrmann model was not selected for inclusion in this study. The Wehrmann model also does not evaluate renovation of the effluent by soils. However, since several of the soil groups in New Jersey have very limited or no renovation capacity (Robert Hordon, 1987), this was not considered to be a significant omission.

3. DERIVATION OF THE DILUTION MODEL

Trela and Douglas (1978) developed a formula to calculate what they termed the carrying capacity of given area. The carrying capacity is defined as the smallest lot size, in acres per person, on which a conventional septic system can be operated without raising the groundwater nitrate concentration above the set standard. This formula was of the form:

$$\frac{V_e C_e}{(V_i + C_i)\, C_q} = H \qquad (1)$$

where:

$\underline{V_e}$ = volume of septic effluent entering system
$\underline{C_e}$ = concentration of nitrate in septic effluent
V_i = volume of infiltrating precipitation
C_i = concentration of nitrate in precipitation
C_q = selected water quality standard for nitrate
H = carrying capacity

The term for V_e was expanded for use in this model to account for researched values of wastewater flow per person per day (Q_p), converted into gallons/person/year, and number of persons per household (P). This allows calculations of H in terms of acres per household, a more useful number for planning purposes. Also, the term for V_i was modified to allow the use of commonly-available infiltration values reported in inches per year (R_i). The formula thus used in this nitrate dilution model is:

$$H: \frac{365Q_pP(C_e-C_q)}{(27{,}154.29R_i)\ C_q} \qquad (2)$$

If the parameters on the right side of the equation can be quantified for a given area, the formula will calculate the minimum lot size acceptable for use with conventional onsite wastewater disposal that theoretically will avoid increasing the nitrate concentration in groundwater above the selected standard.

As stated, the final concentration of nitrate entering a surface water body from groundwater discharging to streams is a function of the natural environment, and of demography. Therefore, the supportable housing density for an area is also a function of these factors. To calculate the supportable housing density, careful selection of the variables used in the model is essential.

4. PARAMETER SELECTION AND IMPLICATIONS FOR MODEL APPLICATION

Simulation of a real-world situation by a model necessarily implies some compromise on the amounts and accuracy of the data used in the model. For the nitrate dilution model described in the previous section, the values selected for each input parameter should be as complete and representative of the natural and man-made systems being simulated as possible. If such data are not available, a good understanding of the significance of each variable on model output must be obtained so that the effect of less-than-ideal data can be correctly understood.

During development of this model, earlier attempts to identify and collect sufficient data for all input parameters were not completely successful, mainly because the data required have not been developed on a state-wide basis, or because the natural systems being modeled are extremely variable. Applications of this model to similar large-scale areas (e.g., counties, watersheds, municipalities) may experience similar problems with selecting appropriate values for certain parameters. Therefore, the following paragraphs discuss the significance of each variable used in the model and suggest methods for selecting values for them.

Wastewater Discharge, Q_p. This number represents the average daily water usage per person, measured in gallons per day. Several values for this parameter were found in the literature, ranging from 65 gallons per day to 100 gallons per day, with no commonly-selected value apparent. Since this model is intended to be conservative, a value of 100 gallons per day is used; this is equivalent to a frequently-used flow rate for designing septic systems and is considered to be representative of daily water usage by Pizor and others (1983).

Residents per home, P. A value of 3.75 persons is considered to be representative of average household size (Pizor, Nieswand, and Hordon 1983).

Nitrate concentration in effluent, C_e. Measured in mg/l, this parameter represents the average concentration of nitrates discharged to area aquifers through conventional on-site septic systems. In this study, the selected value represents the concentration of nitrate available for dilution, assuming that no natural nitrate renovation will occur. This is the case for at least half of the State, with permeable, sandy soils containing little or no organic materials (Hill, 1972; Hordon, 1987). The selected value of 40mg/l represents the average nitrate concentration in septic effluent with no renovation (Canter and Knox, 1984).

Renovation refers to the natural capacity of the soil to remove contaminants from water as it percolates through the unsaturated zone. Proteinaceous materials which enter the septic tank are broken down into ammonium and organic nitrogen; the organic nitrogen is converted by bacteria to ammonium (Freeze and Cherry, 1979). In the aerobic conditions which prevail under most septic systems, most of the ammonium is quickly oxidized to nitrate.

If the soils under the septic drainfield are rich in clay, some of the ammonium may be adsorbed onto the charged surfaces of the clay minerals. However, research on soils in Connecticut found that soils which had an initial renovation capacity of up to 30 percent lost almost all of their renovation capacity after two years (Hill, 1972). This loss was attributed to a reduction in the organic content of the soil and the cation exchange capacity of the clays. Similar results were found by Starr and Sawhney (1980) who concluded that after as little as two years, nitrogen and carbon from a septic system drainfield are transported through the unsaturated zone to the water table with essentially no renovation. In general, these studies have indicated that most nitrate renovation occurs in the upper few feet of soil through utilization of plants and denitrification. Once nitrates have moved through the top three to four feet of soil, the possibility of chemical denitrification is unlikely (Avnimelech and Raveh, 1976; Bouwer, 1976; Caroline County Comprehensive Water and Sewer Plan, 1987).

Under typical conditions, renovation of nitrates in septic effluent may be further reduced because the system drainfields are installed a few feet below ground. Effluent discharging from the drainfield thus may bypass some of the soil horizon which has the most renovating capacity. Migration of groundwater and associated contaminants is very rapid in the unsaturated zone (Freeze and Cherry, 1979), and there is little time for chemical interactions to occur. Therefore, soil renovation of nitrate is not considered to be a significant source of dentrification for the purpose of this model.

Infiltration (recharge), R_i . Measured in inches per year, this number represents the quantity of precipitation that infiltrates the shallow aquifer and is available to mix with groundwater and septic effluent. In hydrologic terms, R_i equals total precipitation minus runoff and evapotranspiration. The quantity of water that infiltrates is also a function of the underlying geology, which affects the rate at which infiltration can reach shallow groundwater. The values used in the model are based on available climatic and hydrogeologic information for the State and are considered to be representative of infiltration for the aquifer units used in the model. The selected values and the references used to determine them are presented in the following section of this report. The value of R_i is multiplied by 27,154.29 in the model to convert inches per year to gallons per acre per year.

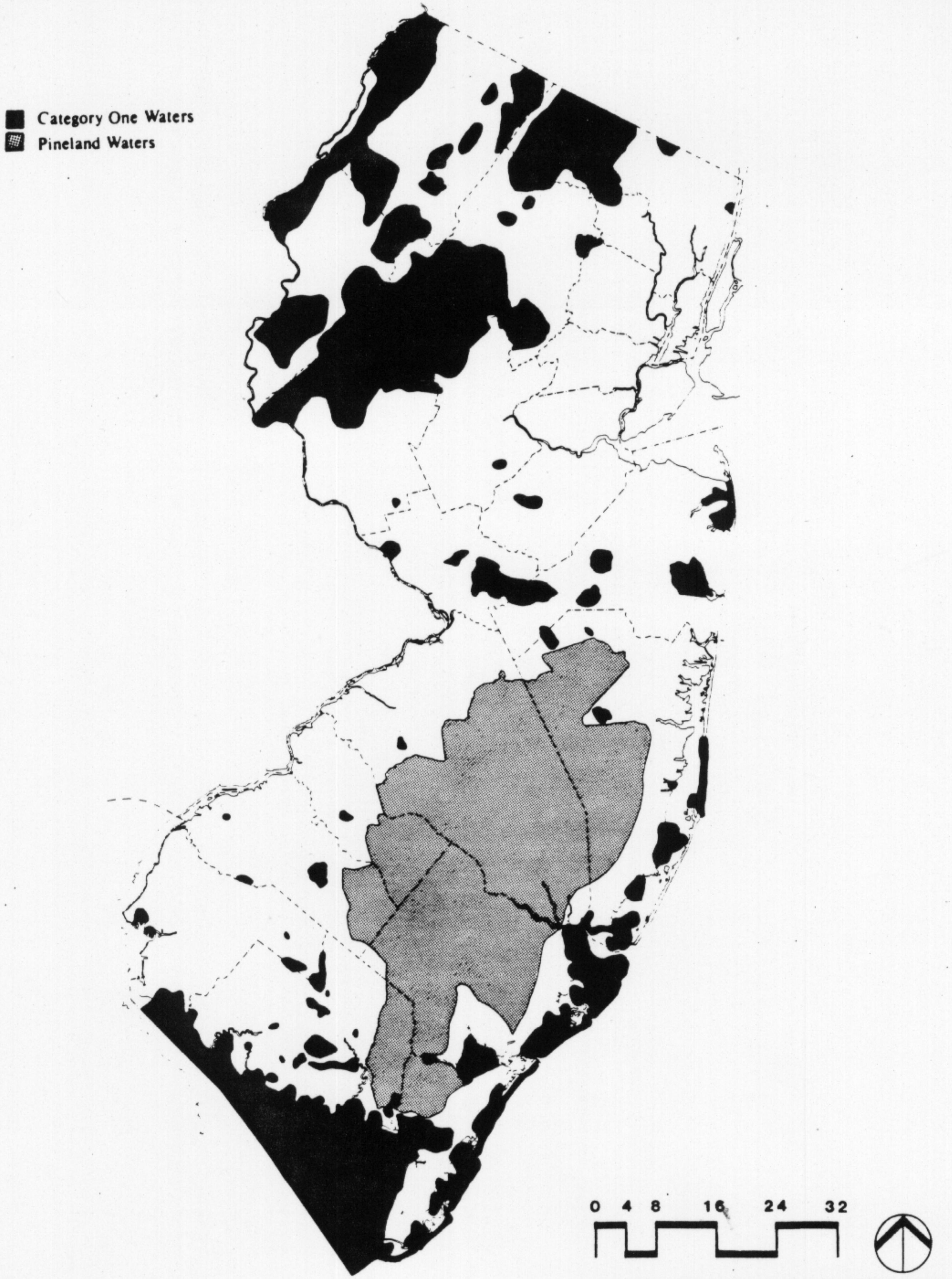
Water quality standard, C_q. As mentioned previously, several water quality standards for nitrate have been set by various regulatory agencies. The current drinking water standard, specified by the Safe Drinking Water Act regulations (40 CFR 141), is 10 mg/l. However, studies of nitrate contamination on Long Island (Hughes, Pike, and Porter, 1985) strongly suggest that the standard for groundwater should be set at a lower level to ensure that the drinking water standard is not violated frequently. In fact, this has been done in New Jersey, where a 2mg/l standard was adopted for the pine barrens region (New Jersey Pinelands Commission, 1980).

The NJDEP-Division of Water Resources recommends that a target water quality standard of 5 mg/l be used in applying this model (NJDEP, Division of Water Resources, 1988). This approach builds in a certain amount of conservatism to compensate for imprecise data inputs and model assumptions. In addition, utilizing a 5 mg/l standard is consistent with the anti-degradation policy contained within the State's water pollution control act.

Alternative standards may also be chosen for certain watersheds, depending on existing water quality maintenance goals for the area. Areas in the State which are distinguished as high-quality waters meriting protection under State water pollution control act are Category I waters and trout production waters. Water quality parameters in waters that generally fall below the water quality criteria (except as due to natural conditions) should be improved to maintain designated uses where this can be accomplished without adverse impacts on organisms, counties, or ecosystems of concern. Figure 4-1 shows watersheds which contain Category I water; this information was compiled from 1:24,000 USGS quadrangle data available from the NJDEP-Division of Water Resources. Trout production waters are included in the State's water quality standard as Category I waters, since healthy trout populations require cool, clear, oxygen-rich water free of serious pollution. Figure 4-2 shows watersheds that contain trout production waters.

Approximately 40 percent of the State's population is served by surface waters. Thirty reservoirs are currently in use or considered for emergency supply, and five are under construction or proposed. Figure 4-3 shows watersheds that contain existing or proposed reservoirs; this map was prepared from the NJDEP 1:250,000 drainage basin map and the above quadrangle data. Water supply and quality are a critical concern to the State, particularly for those reservoirs that supply the most densely-populated areas of the State. Over 61 percent of the threatened and endangered plant species and 83 percent of the threatened and endangered animal species in the State are associated with aquatic habitats (NJDEP, 1980); therefore, some consideration of the water quality in these areas is also necessary.

In the Pinelands Comprehensive Management Plan (New Jersey Pinelands Commission, 1980), a target water quality standard of 2 mg/l is used. Based on a review of surface water quality data, the Pinelands nitrate levels are some of the lowest in the State. A slightly higher standards of 3 mg/l as a target would be supportable in other areas of the State where the objective is to maintain high-quality water, because the USGS has reported that nitrate rarely occurs naturally in groundwater in concentrations greater then 3 mg/l (USGS, 1984). Correlation of surface water quality data (USGS, 1985) with Category I waters (including trout production and maintenance) in New Jersey further substantiates this conclusion.



Surface Water Quality

Figure 4-1

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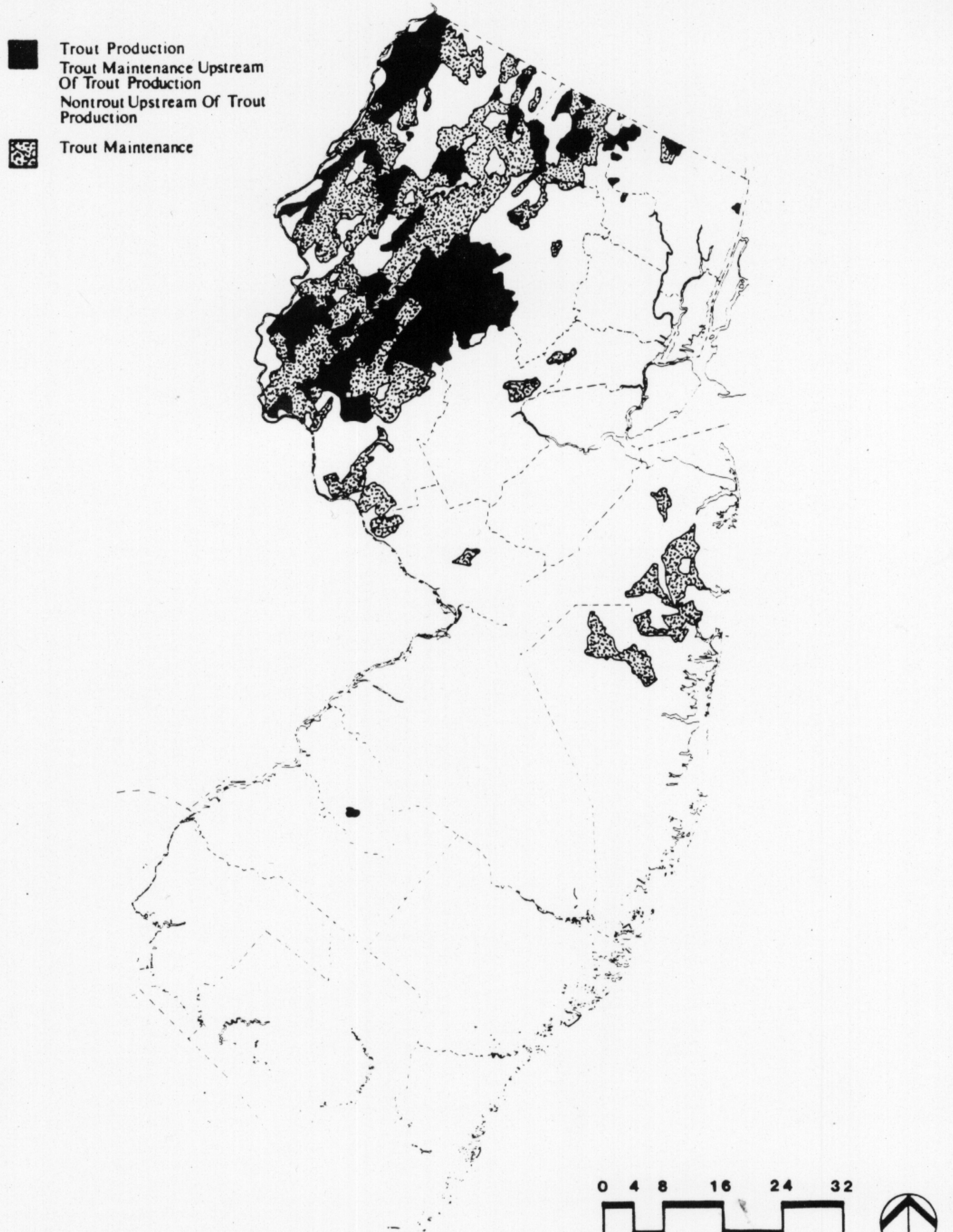

Trout Waters

Figure 4-2

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Water Resources

Figure 4-3

RGH

The parameter values that were reviewed and selected for use in this dilution model were, for the most part, based on documented values for the different variables that had to be defined. For infiltration, a range of values is reported, either because of a lack of data in a specific area, a wide range of values for the same area, and the fact that the model is being applies to the entire State as an approximation of more specific conditions.

5. USE OF THE MODEL FOR REGIONAL PLANNING IN NEW JERSEY

The nitrate dilution model developed in this study for use in New Jersey can estimate a recommended average housing density for an area of up to several square miles, based on the overall environmental conditions of that area. To provide meaningful simulations of these areas, they were defined to as small a scale as possible, primarily on the basis of geologic and hydrologic variations throughout the State. These simulation areas are termed management units.

To respond to the most significant input variables in the model, the management units were selected to distinguish between variations in infiltration (R_i) and the selected water quality standard (C_q). The most readily defined areas that can account for differences in these parameters are aquifer types and watersheds. Aquifer types (e.g., sands, shales) partly control the amount of infiltration because of their differing hydrogeologic characteristics. Watersheds are the areas within which water quality standards for Category I and other sensitive waters are defined by the State.

From examination of the State geologic map, the aquifer types were defined as groups of geologic formations that share the same general hydrogeologic characteristics. These aquifer types are presented in Table 5-1. Individual mapped watershed in the State were superimposed on the State geologic map to determine which aquifer types were present at the surface in each of the watersheds.

Each aquifer/watershed group was considered to be one “management unit”. Where more than one predominant aquifer formation is present in a watershed, the watershed was subdivided into several management units along the boundaries of each aquifer type. The mapped management units are presented in Appendix A and B of this report.

Representative values for filtration for the different aquifer types were selected on the basis of information provided in various publications and through consultation with experts in the NJDEP-Division of Water Resources (1988); these values (and the associated references) are also presented in Table 5-1.

As discussed in the previous section, the water quality standard selected for the model in 5 mg/l, based the recommendation of DEP-Division of Water Quality. However, if the watershed contains Category I or other ecologically significant waters, a 3 mg/l standard is used within the watershed.

Table 5-1: Aquifer Types and Representative Values for Infiltration

Aquifer Type	Geologic Unit (Atlas Sheet 40)	Normal R(i) (in/yr)	Conservative R(i) (in/yr)
Best Coastal Sands	Cohansey Sand (Tch)	20	15
	Kirkwood Sand (Tkw)		
	Magothy and Raritan (Kmr)		
Regular Sands	Vincentown Sands (Tvt)	18	12
	Mount Laurel/Wenonah (Ktw)		
	Englishtown (Ket)		
	Beacon Hill Gravel (Tch)		
	Red Bank/Tinton Sands (Krb)		
Sandstone/Shale	Brunswick Formation (Trb)	10	9
	Stockton Formation (Trs)		
	Bellvale & Pequanack (Dbp)		
	Kancuse Sandstone (Dkn)		
Limestone	Kittantinny Limestone (Cok)	12	10
	Onondaga Limestone		
	Jacksonburg Limestone (Ojb)		
	Devonian/Helderbergs		
	Oriskany and Bedcraft		
	Becker/Bossardville/Manlius/ Rondout/Poxino Island (Sbd)		
Argillite/	Lockatong Formation (Trl)	5	3
Coastal Aquitards	Shark River Marl (Tsr)		
Conglomerate	Manasquan Marl (Tmq)		
	Hornerstown Marl (Tht)		
	Navesink Marl (Kns)		
	Marshalltown Formation (Kmt)		
	Woodbury Clay (Kwb)		
	Merchantville Clay (Kmv)		
	Shawangunk (Ssg)	10	6
	Green Pond (Sgp)		
	Hardyston (Ch)		
	Skunnemunk (Dsk)		

Table 5-1: (cont'd)

Aquifer Type	Geologic Unit (Atlas Sheet 40)	Normal R(i) (in/yr)	Conservative R(i) (in/yr)
Crystalline/Shale/ Siltstone	Losee Gneiss (lgn) Byram Gneiss (bgn) Pochuck Gneiss (pgn) granite (gr) gabbro (gb) Wissahickon Mica Gneiss (wgn) Martinsburg Shale (Omb) High Falls Formation (Shf) Marcellus Shale	8	4
Diabase/Basalt/ Quartzite	basalt flows (Trbs) diabase (Trob) Esopus Grit (Des)	4	2
References:	Barksdale, 1958; 1943 Carswell and Hollowell, 1968 Disko, Nusser, and Doheny, 1978 Farlekas, 1979 Geraghty and Miller, 1978 Gill and Vecchioli, 1965 Gill, 1962 Greerman, Rima, Lockwood, and Meisler, 1961 Harbaugh and Tilley, 1984 Hardt and Hilton, 1969 Kasabach, 1966 Lang and Rhodehamel, 1963	Luzier, 1980 Nemickas, 1976 Nichols, 1977 Posten, 1982 Poth, 1970 Rhodehamel, 1970 Rush, 1968 Trela and Douglas, 1978 Vecchioli and Miller, 1973 Vecchioli, 1973 Wood, Flippo, and Lescinsky, 1972 Wright Associates, 1982	

In reviewing numerous case studies of nitrate contamination by septic effluent (e.g., Ragone and others, 1981; Canter and Knox, 1984), and through discussions with water quality and land planning experts in New Jersey, it became apparent that disposal f wastewater by conventional septic systems on lots of less then one acre would likely cause contamination problems. Therefore, on the basis of these studies and the experience of other workers, the minimum lost size calculates by the model is one acre. It is significant to note that for the input parameters selected for use in the state-wide-model, none of the calculated lot sizes were less than one acre.

Using the range values given for infiltration in Table 5-1 and the other input parameter values as described above, values for supportable housing density, H, were determined for the management units delineated in the mapping process throughout New Jersey. These values are shown in Appendix A and B of this report in tabular. A summary of the calculated lot sizes is shown in Figure 5-1.

Calculated Lot Sizes

by Aquifer Type

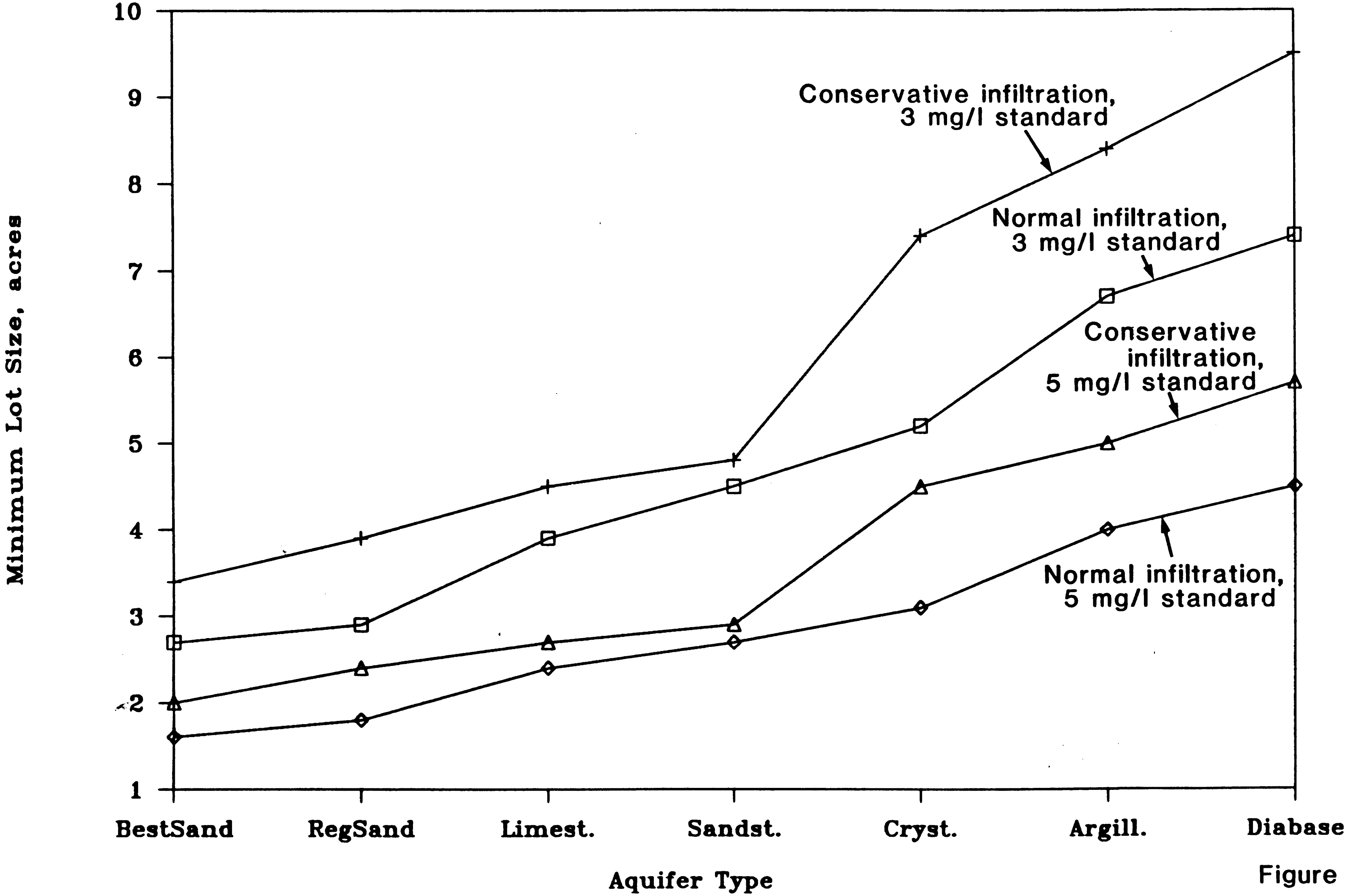

Figure 5-1

RGH

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APPENDIX A: Example Model Runs: 3 mg/l Water Quality Standard

Date of Run: December 6, 1988	Supportable	INPUT PARAMETERS				Effluent	Recharge
Aquifer Type/ Parameters	Housing Density (acres/lot)	Q(p) gpp/day	P per home	C(e) mg/l	R(i) in/yr	Volume V(e) gpp/yr	Volume V(i) gal/ac/yr
Argillite/Coastal Aquitards/Conglomerate							
Normal Parameters	**12.4**	100	3.75	40	5	136,875	135,771
Conservative Parameters	**20.7**	100	3.75	40	3	136,875	81,463
Best Coastal Sands							
Normal Parameters	**3.1**	100	3.75	40	20	136,875	543,086
Conservative Parameters	**4.1**	100	3.75	40	15	136,875	407,314
Crystalline/Shale/Siltstone							
Normal Parameters	**7.8**	100	3.75	40	8	136,875	217,234
Conservative Parameters	**15.5**	100	3.75	40	4	136,875	108,617
Diabase/Basalt/Quartzite							
Normal Parameters	**15.5**	100	3.75	40	4	136,875	108,617
Conservative Parameters	**31.1**	100	3.75	40	2	136,875	54,309
Limestone							
Normal Parameters	**5.2**	100	3.75	40	12	136,875	325,851
Conservative Parameters	**6.2**	100	3.75	40	10	136,875	271,543
Regular Coastal Sands							
Normal Parameters	**3.5**	100	3.75	40	18	136,875	488,777
Conservative Parameters	**5.2**	100	3.75	40	12	136,875	325,851
Sandstone/Shale							
Normal Parameters	**6.2**	100	3.75	40	10	136,875	271,543
Conservative Parameters	**6.9**	100	3.75	40	9	136,875	244,389

APPENDIX B: Example Model Runs: 5 mg/l Water Quality Standard

Date of Run: December 6, 1988	Supportable	INPUT PARAMETERS				Effluent	Recharge
Aquifer Type/ Parameters	Housing Density (acres/lot)	Q(p) gpp/day	P per home	C(e) mg/l	R(i) in/yr	Volume V(e) gpp/yr	Volume V(i) gal/ac/yr
Argillite/Coastal Aquitards/Conglomerate							
Normal Parameters	**7.1**	100	3.75	40	5	136,875	135,771
Conservative Parameters	**11.8**	100	3.75	40	3	136,875	81,463
Best Coastal Sands							
Normal Parameters	**1.8**	100	3.75	40	20	136,875	543,086
Conservative Parameters	**2.4**	100	3.75	40	15	136,875	407,314
Crystalline/Shale/Siltstone							
Normal Parameters	**4.4**	100	3.75	40	8	136,875	217,234
Conservative Parameters	**8.8**	100	3.75	40	4	136,875	108,617
Diabase/Basalt/Quartzite							
Normal Parameters	**8.8**	100	3.75	40	4	136,875	108,617
Conservative Parameters	**17.6**	100	3.75	40	2	136,875	54,309
Limestone							
Normal Parameters	**2.9**	100	3.75	40	12	136,875	325,851
Conservative Parameters	**3.5**	100	3.75	40	10	136,875	271,543
Regular Coastal Sands							
Normal Parameters	**2.0**	100	3.75	40	18	136,875	488,777
Conservative Parameters	**2.9**	100	3.75	40	12	136,875	325,851
Sandstone/Shale							
Normal Parameters	**3.5**	100	3.75	40	10	136,875	271,543
Conservative Parameters	**3.9**	100	3.75	40	9	136,875	244,389