Nitrate Dilution Modeling of Montgomery Township,
Somerset County, NJ

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April 8, 2004
**Introduction**

Nitrate from natural sources generally only occurs in ground water at low levels but anthropogenic sources can lead to elevated concentrations. Sources include fertilizers, animal waste, and sewage effluent. Nitrate is considered a contaminant in ground water because of various impacts to human health and aquatic ecology. For instance, high levels of nitrate intake in infants can lead to methemoglobinemia, or blue baby syndrome (Hem, 1985; U.S. EPA, 1991). Because of its low natural occurrence and solubility and stability in groundwater, nitrate can also serve as an indicator for possible bacterial, viral, or chemical contaminants of anthropogenic origin.

Nitrogen is present in septic system effluent and is converted to nitrate through biological processes active in the soil below the drain field. Once this nitrification process is complete, nitrate is a stable and mobile compound in ground water under normal conditions (Hoffman and Canace, 2001). Nitrate concentrations resulting from septic effluent are mitigated by dilution if the septic effluent is combined over time with water entering the ground through infiltration during and after storm events. The extent of this dilution effect is clearly dependent on long-term rates of both infiltration and nitrate loading from septic system sources. The density of septic systems relative to infiltration rates in a particular area is therefore a critical factor controlling the ultimate nitrate level in ground water.

The purpose of this report is to present the results of nitrate dilution calculations for Montgomery Township in Somerset County, New Jersey. Two different methods were explored, and the results of both are presented and explained.

**Physical Setting: Montgomery Township**

Montgomery Township lies entirely in the Piedmont physiographic province of New Jersey. Bedrock formations within the Piedmont are of Late Triassic and Early Jurassic age (230 to 190 million years old) and are part of the Newark Supergroup. Three formations of the Newark Supergroup are present in Montgomery: from oldest to youngest, the Stockton, Lockatong, and Passaic, which is part of the Brunswick Group (Figure 1). These formations crop out as a northeast-striking belt of rocks, with a gentle northwesterly dip of about 15 degrees. The sequence of three sedimentary units (Stockton, Lockatong and Passaic) is disrupted in the area surrounding Montgomery as a result of vertical displacement along the Hopewell Fault, which extends northeast through the area and passes through the western portion of the Township. In addition, later diabase rocks of Jurassic age cut through the sequence of sedimentary rocks within the Township (USGS, 1998).
The Stockton Formation consists of red and gray thin-bedded to thick-bedded, very fine-grained to coarse-grained sandstone, siltstone, and shale. The Lockatong Formation is composed of dark gray and reddish-brown beds of siltstone and shale with minor amounts of fine-grained sandstone. Many of the siltstone and sandstone beds are extremely hard, chemically cemented siltstone and sandstone (argillite). Rocks of the Lockatong Formation are generally more resistant to erosion than are adjacent units and therefore form ridges, such as the face of the Sourland Mountains. The youngest and most abundant rock in the region is the Passaic Formation. It consists of reddish brown, thin-bedded to thick-bedded shale, siltstone, and very fine-grained to coarse-grained sandstone. In addition, some zones of dark gray siltstone are present, similar to those of the underlying Lockatong Formation. The diabase (trap rock) is a fine-grained to coarse-grained, dark gray to black igneous rock, which has intruded between the beds of the Newark Supergroup sediments. It is extremely hard and resistant to weathering. Diabase is found at the top of the Sourland Mountains and also forms a topographic feature known as the Princeton Ridge, which extends east-west from Rocky Hill to Mount Rose (Lewis-Brown and Jacobsen, 1995).

Soils of the Northern Piedmont Lowland are dominantly silty and commonly shaly or stony. Most of the soils are underlain by hard bedrock at a depth of 2 to 20 feet (USDA SCS, 1972). The dominant soil in Montgomery Township is the Penn (Figure 2). It consists of reddish-brown, moderately deep (20 to 40 inches to bedrock), well-drained soils formed in materials weathered from noncalcareous reddish shale, siltstone, and fine-grained sandstone normally of Triassic age. Penn soils are on nearly level to steep and moderately dissected uplands.

Other soils derived from shale, siltstone, slate and/or sandstone, associated with the Penn series are the shallow (10 to 20 inches to bedrock) Klinesville series, the moderately deep (20 to 40 inches to bedrock) Reaville series, and the very deep (depth to stratified sand and gravel more than 40 inches) Rowland series formed in alluvial sediments. These reddish brown soils fall into the group of soils with moderately fine to fine textures, impeding the downward movement of water. Another extensively occurring series in the Township is the Chalfont series. These soils, found on the slopes of the Sourland Mountains, are deep to very deep (3½ to 8 feet or more), soils formed in a loess mantle overlying a weathered residuum of shale and sandstone. They are somewhat poorly drained with medium to fast runoff and slow permeability (USDA NRCS, 2003).

In the context of septic system operation and nitrate dilution, a significant characteristic of the soils of much of Montgomery Township is that they very often do not have sufficient percolation rates in the soil horizons to support septic drain fields. In response to this, septic fields are often installed by excavating deeper than usual into a zone that is predominantly weathered bedrock to achieve the necessary percolation rates. This is important because it means that the septic system effluent is being released very near the upper surface of the fractured bedrock that serves as an aquifer. In this situation, there is a significant possibility that septic system effluent will migrate to a fracture in the
bedrock and pass downward into the aquifer (Mulhall, pers. comm.). The impact of this on nitrate dilution is discussed below.

**Methods**

*Recharge and Nitrate Dilution Processes*

The hydrologic cycle describes the balance and distribution of water as it moves through various processes between the atmosphere, surface water, and ground water. Precipitation forms in the atmosphere and falls to the earth’s surface, moves through streams, rivers, and groundwater, flows to the ocean, and is returned to the atmosphere through evaporation and transpiration by plants. It is the part of this cycle in which water enters the ground that is of interest in evaluating nitrate dilution. Precipitation reaching the ground enters several pathways in the cycle.

- Plant leaves intercept a portion and it is either taken up by the plants or immediately returned to the atmosphere by evaporation.
- Of the remainder that reaches the ground, some flows away as overland runoff and eventually flows into streams.
- Some water remains on the surface and evaporates back to the atmosphere.
- The rest infiltrates into the soil, but does not necessarily enter an aquifer. A great deal of the infiltrated water is taken up by plant roots and ultimately returned to the atmosphere by the plants through transpiration.
- Beyond the root zone, water continues to move downward if conditions allow. For this report, the quantity of water that moves downward beyond the root zone is called **soil recharge**.
- In conditions such as those found in Montgomery Township, some of this water finds its way into fractures in the bedrock and moves downward into the bedrock aquifer. This quantity of water is referred to as **aquifer recharge**.
- Because the amount of water that can enter through fractures is limited, a significant amount stays above the top of the bedrock and moves laterally through the soil, eventually discharging back to surface water through seeps or directly into streambeds. This process is known as **interflow**.

The central assumption of nitrate dilution calculations is that over the long term, septic system effluent is diluted by fresh water infiltrating the ground after a storm. But in order to properly calculate the dilution, we must correctly identify where in the hydrologic cycle the dilution is occurring. The key question is whether the septic system effluent is diluted by the full quantity of soil recharge water and eventually divided into interflow and aquifer recharge, or whether the effluent does not move as interflow and is only diluted by the quantity of recharge water that actually enters the aquifer.
**NJGS Method**

New Jersey Geological Survey (NJGS) has produced a model for calculating nitrate dilution from septic systems that is documented in Hoffman and Canace, 2001. The NJGS model is a synthesis of two independent models: one for calculating “ground water” recharge, published by NJGS and known as GSR-32 (Charles, et al., 1993) and a modified version of the Trela-Douglas mass dilution model (Trela and Douglas, 1978).

The GSR-32 method estimates soil recharge based on soil type, impervious cover, and annual rainfall. Although the GSR-32 publication uses the term “ground water,” the term soil recharge is used here in an attempt to avoid confusion that commonly occurs in discussing the various models. The GSR-32 method is designed to estimate how much of the annual rainfall enters the soil and infiltrates past the root zone. In other words, it estimates how much of the rainwater is left after the amount that runs off over land and the amount that is returned to the atmosphere through evapotranspiration. It does not include any mechanism for estimating how much of the infiltrated water reaches the bedrock aquifer and how much moves laterally in the soil zone and ultimately returns to surface water bodies (the process known as interflow). As we will see, this difference can be substantial, particularly in areas with fractured bedrock aquifers.

The NJGS nitrate dilution method uses GSR-32 recharge values as a starting point. It then calculates nitrate dilution and from that a minimum number of acres per septic system necessary to provide adequate dilution to stay below a target maximum nitrate concentration in groundwater, which is a value specified by the user. (The default configuration of the model uses a target value of 10 mg/liter, which coincides with the primary drinking water standard.) Based on the minimum lot size, a resulting value of impervious cover is calculated. Since impervious cover reduces recharge and therefore affects the dilution calculation, that value is then used to repeat the calculations, and an iterative process is used until the model reaches a stable solution (Hoffman and Canace, 2001).

**Aquifer Recharge Method**

With a traditional septic system installation, the effluent from the drain field is released into the soil zone. From there it migrates downward and possibly laterally, depending on local conditions. But whereas a significant portion of the rainwater infiltrating the soil zone ends up moving laterally as interflow and never reaching the aquifer, the same does not necessarily happen with the septic system effluent. During dry periods, the septic system effluent is the only water moving down through the soil zone. Because the quantity of water percolating down is so much less than during rainfall periods, in some settings, nearly all of it may enter the aquifer.

In addition to this, as mentioned above, septic system drain fields in many cases in Montgomery (and in the region in general) are essentially installed at the bottom of the soil zone, and the septic effluent discharges into a zone of weathered bedrock. In these
circumstances, the possibility exists in any given case for the effluent to reach a fracture in the bedrock directly. This would lead to an even higher percentage of the effluent entering the bedrock aquifer (especially in dry periods) and a lower percentage being diverted as interflow. In such a case, it is more appropriate to calculate nitrate dilution based on the quantity of recharge entering the bedrock aquifer rather than the quantity that enters the soil. Therefore, this report also includes the results of nitrate dilution calculations that are based on *aquifer* recharge rates rather than the *soil* recharge rates that come from the GSR-32 method. The rates of aquifer recharge used here are from analyses performed by M2 Associates (Mulhall, 2001 and Mullhall, pers. comm.).

Mulhall (2001) derived values for aquifer recharge for the formations that underly Hopewell Township, and has since refined the results of that analysis and extended it to include Montgomery (Mulhall, pers. comm.). The recharge estimates are based on a mass balance approach in which evapotranspiration and surface runoff are subtracted from precipitation. This is similar to the basic approach of GSR-32, except that interflow, the lateral movement of water within the soil zone, is considered as surface water runoff along with the overland flow component. Interflow and overland flow are combined in the analysis because neither can be measured directly but both ultimately contribute to stream flow, which can be measured directly. Overland flow contributes to stream flow during and immediately after a storm event. Interflow through the soil is what causes stream flows to remain high for a number of days after a storm event. Long after a storm, the flow in streams is provided by discharge from groundwater. By analyzing long-term climate and stream flow records and interpreting the results of computer models of groundwater flow, Mulhall arrived at estimates for evapotranspiration and the combination of overland runoff and interflow. Subtraction of these values then yields an estimate for aquifer recharge.

The difference between this approach and the one taken by GSR-32 is that GSR-32 considers that any water that infiltrates the soil zone and isn’t taken up by plants is a contribution to groundwater. But stream flow records clearly show that most of that soil recharge does ultimately end up back in the surface water and never reaches the water table aquifer in bedrock.

Aquifer recharge values were used with the Trela-Douglas formula for nitrate dilution, the same formula that is the basis for the NJGS method. One modification to the original Trela-Douglas formula that is incorporated in the NJGS method was not used, however. The NJGS method adjusts the formula to account for the reduction in soil recharge caused by impervious cover. In the case of aquifer recharge, however, this relationship is less clear. In the setting in question, with a fractured bedrock aquifer covered by layers of soil, most of the water that enters the soil travels laterally along the soil-rock interface as interflow and never enters the aquifer. If the volume of water entering the soil is reduced by a small percentage, it is not clear how much the volume that enters the aquifer will be reduced, and at the housing densities in question here, the impervious cover percentages would be relatively low. We therefore base the dilution calculations on the aquifer recharge estimates that reflect current conditions, without a reduction for a projected effect of increased impervious cover.
The equations from the Trela-Douglas model start from the basic assumption that nitrate entering into the site from septic systems on an annual basis is equal to nitrate leaving the site in groundwater, diluted by recharge (Hoffman and Canace, 2001). The equation takes the form of

\[ H M = A R C \]

Where

- \( H \) = People per home
- \( M \) = Per capita nitrate loading rate (10 lbs/year)
- \( A \) = Area of land over which recharge occurs
- \( R \) = Recharge rate
- \( C \) = Concentration of nitrate in groundwater (5.2 mg/liter)

After the appropriate conversion factors are applied to equalize the units involved, and incorporating the constant values listed above and rearranging the equation to solve it for area, it becomes

\[ A = \frac{25.48}{R} \]

Where

- \( A \) = Area of land, in acres
- \( R \) = Recharge rate, in inches/yr

This form of the equation provides a straightforward relationship between the rate of aquifer recharge and the minimum land area necessary to provide adequate dilution for one septic system (assuming three people per household and the other constants listed above).

**Results and Discussion**

**NJGS Method**

Soil recharge values produced using version 5.0 of the NJGS method are displayed in Figure 3; projected values for minimum average lot size per septic system are in Figure 4. These are based on the following parameter selections. Number of people per home was set at 3, based on data from the 2000 census. The target nitrate concentration after dilution was 5.2 mg/l, which is the default value recommended by the model’s authors as consistent with the antidegradation approach defined in New Jersey’s ground water quality regulations (N.J.A.C 7:9-6). Climate values were the standard values in the model for Montgomery Township, and nitrate loading rate was 10 pounds per person annually, also the model’s standard value.

Because the NJGS method is based primarily on soil type, and most of the soils in the Township have similar drainage characteristics, there is very little variability in the
results from place to place within the Township. Excluding areas with wetlands or hydric soil (for which the NJGS method cannot compute results), values of minimum lot size range from 2.0 to 2.4 acres per septic system.

It is important to keep in mind that the NJGS model is not designed to estimate nitrate concentrations in specific places arising from individual systems; rather, it is meant for estimating on a regional basis what the cumulative impact is of a number of systems taken together. It is designed to be applied at a map scale of 1:24,000, which means that it is not appropriate to use the model to discern fine differences occurring over small distances. For this reason, it would be appropriate to use a statistical function to smooth out some of the fine-scale variations in the results. We have not presented results of that process here for two reasons. First, there is very little variation in the results to begin with. Second, and much more important, the specific conditions that exist in the Township are such that the model is simply not appropriate to the setting. As described above, site conditions often lead to situations where septic system effluent can ultimately move primarily into the bedrock aquifer with very little diverted as interflow. But of the quantity of recharge water estimated to enter the soil by the GSR-32 method, the great majority does ultimately get diverted as interflow and a relatively small proportion enters the aquifer where it would serve to dilute the septic effluent (compare Figures 3 and 5). Furthermore, there is evidence from streamflow records for the area that the estimates of soil recharge produced using GSR-32 are too high, even leaving out the question of soil recharge vs. aquifer recharge (Mulhall, 2001.) For these reasons, it is more appropriate to use aquifer recharge estimates as the quantity of water available to dilute septic system effluent.

**Aquifer Recharge Method**

As described earlier, there are four geologic formations underlying Montgomery Township. From oldest to youngest, they are the Stockton, Lockatong, and Passaic Formations and intrusions of Jurassic Diabase. Median annual recharge rates for these aquifers are as follows. These values are also shown as they are distributed over the Township in Figure 5.

<table>
<thead>
<tr>
<th>Geology</th>
<th>Aquifer Recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockton Formation</td>
<td>5.5 inches/yr</td>
</tr>
<tr>
<td>Lockatong Formation</td>
<td>2.2 inches/yr</td>
</tr>
<tr>
<td>Passaic Formation</td>
<td>5.5 inches/yr</td>
</tr>
<tr>
<td>Jurassic Diabase</td>
<td>2.2 inches/yr</td>
</tr>
</tbody>
</table>

Using the methodology described above, the resulting values for the land area necessary to provide adequate dilution for each septic system are as follows. Figure 6 shows these values as they occur within the township.
Geology | Maximum Septic System Density
---|---
Stockton Formation | 4.6 acres/system
Lockatong Formation | 12 acres/system
Passaic Formation | 4.6 acres/system
Jurassic Diabase | 12 acres/system

It should be noted that the recharge values listed above are average values for the geologic formations. Since the recharge is occurring through fractures in the rock, site-specific conditions can have a large effect on the process. Areas that have a higher density of fractures will have higher recharge rates than those with lower fracture densities. In particular, the Hopewell Fault has been identified as an area with substantially higher recharge than the surrounding areas. Recharge through this approximately 500-foot-wide fracture zone into the Passaic Formation has been estimated to be as high as 95 inches per year (Lewis-Brown and Jacobsen, 1995; Mulhall, 2001). Purely on the basis of nitrate dilution, it might be tempting to conclude from this that the fault zone would be able to support very high development densities, but an area with such high recharge is an extremely valuable and sensitive resource. The fault zone and the area upslope (northwest) from it should be protected from overdevelopment because of its regional importance as a recharge area.

**Existing Housing Densities**

To assess existing conditions in light of the nitrate dilution results, housing densities were calculated for areas not served by sanitary sewers. This was accomplished by using the Township’s GIS-based parcel data (dated July 2003) in conjunction with the bedrock geology information. Each property in the Township’s database is flagged with the ID number of the sewer service area (if any) that it falls within, and there is also a count of existing dwelling units on each property. From this data, the number of dwelling units not served by sewers within each of the four outcrop areas was calculated. This number of dwelling units was divided into the total area to arrive at an overall density value for that geologically defined region of the Township.

<table>
<thead>
<tr>
<th>Geology</th>
<th>Existing Septic System Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lockatong and Diabase (NW)</td>
<td>9 acres/system</td>
</tr>
<tr>
<td>Passaic and Stockton (Central)</td>
<td>7 acres/system</td>
</tr>
<tr>
<td>Diabase in SE</td>
<td>160 acres/system</td>
</tr>
</tbody>
</table>

The developed portions of the diabase area in the southeast portion of the Township are served by sewers; our analysis only revealed two dwelling units in that area that are not in a sewer service area. Therefore the contributing area per septic system is quite large and nitrate dilution is not an issue. In the central portion of the Township that is underlain by the Passaic and Stockton Formations, there is 7 acres of contributing area for each septic system, a value safely above the recommended minimum of 4.6 acres. But in the northwestern portion of the Township, which is underlain by Lockatong...
Formation and Jurassic Diabase, the existing density yields a figure of 9 acres per septic system. The minimum area needed to provide adequate dilution is calculated to be 12 acres per system. This indicates that existing conditions in this area may be leading to degradation of groundwater quality. The actual situation is much more complex than the assumptions incorporated into the nitrate dilution model, but these results are a source of concern. Particular attention should be paid to groundwater issues in this portion of the Township.

Conclusions

One component of ground water protection is limiting the amount of nitrate that enters ground water from septic systems. The density of septic systems that can be supported in an area depends on how much recharge enters the ground water to provide dilution of the nitrate load. Nitrate dilution calculations for Montgomery Township were performed using two different methods. The NJGS method (Hoffman and Canace, 2001) uses a mass dilution method based on the annual rate at which water enters the soil and infiltrates past the root zone. Calculations are based on soil type, impervious cover, and climate (rainfall) data. The NJGS method estimates that soil recharge in the Township ranges from 11.8 to 14.8 inches/yr. The corresponding values for the minimum area necessary to provide dilution range from 2.4 to 2.0 acres/system.

The problem with applying the NJGS method in Montgomery Township is that the specific conditions present in the Township cause the ground water system to behave in a way that violates the assumptions inherent in the NJGS method. The NJGS method assumes that both septic effluent and recharge water are subject to the same partitioning that causes some water to move laterally through the soil above the soil-rock interface and ultimately return to surface water bodies, and some water to move downward into fractures in the bedrock and thus enter the aquifer. If the same proportion of recharge water and septic system water follow these two pathways, then the dilution calculations are valid and should properly reflect the dilution effect of the recharge water. But in locations where the septic systems are installed very low in the soil profile, the discharge from the drain field enters directly into a horizon of weathered bedrock. Depending on the specific geometry of the situation, this effluent may preferentially move into fractures in the rock and then into the aquifer. In this case, the more appropriate calculation to use is one based on aquifer recharge volumes rather than soil recharge. Furthermore, there are indications that the soil recharge calculations arising from the NJGS method are too high for Montgomery in any case, based on analysis of stream flow records.

For these reasons, a second set of results is presented, based on calculations using aquifer recharge volumes determined from analysis of the regional groundwater system by Mulhall (2001). The volume of water that enters the fractured bedrock aquifer is much less than the volume of soil recharge calculated by the NJGS method, and as a result, the land area necessary to provide dilution for each septic system is significantly higher. Values for this minimum land area are 4.6 acres per system in areas underlain by Stockton and Passaic Formation rocks and 12 acres per system in areas underlain by
Lockatong Formation and Jurassic Diabase. An exception to these values exists in the area of the Hopewell Fault. The fault zone has very much higher recharge rates than the surrounding areas, and although nitrate dilution is not a particular issue there, the fault zone is a special resource that should be protected.

It should be noted that these numbers represent what the overall density of septic systems in an area should be to protect ground water. Requiring this amount of land as a minimum lot size for each system is one way to achieve this goal but certainly not the only way; the important thing is that the overall density target be reached in a given area.

In the portions of the Township underlain by Passaic and Stockton Formation geology, the distribution of existing septic systems is less dense than the threshold values yielded by the aquifer recharge modeling method, but planning of future growth in this area should be done with the nitrate dilution issue in mind. In the northwest portion of the Township, however, the existing development already indicates a potential problem. Existing septic system density is such that there is 9 acres of land area per septic system contributing to nitrate dilution, but the model yields a recommended minimum of 12 acres per system. This part of the Township may already be developed beyond the capacity of the groundwater system to assimilate the septic effluent. The geology in that region is especially complex, and the model may not adequately represent that complexity, but the results indicate that there is an issue that requires further attention.
References


Figure 1:
Bedrock Geology of Montgomery Township

Data Sources:
Geology: NJ Geologic Survey CD 00-1
Roads, Municipal Boundary: Montgomery Twp
Figure 3: NJGS Method: Soil Recharge Rates

Recharge, in/yr

- 11.8 - 12.0
- 12.1 - 12.3
- 12.5 - 12.6
- 12.7 - 12.8
- 14.4 - 14.8

- Roads
- Streams

Prepared by:
The GIS Center at Stony Brook
December 2003

Data Sources:
NJGS Nitrate Dilution Model v5.0
Roads, Municipal Boundary: Montgomery Twp
Figure 4: NJGS Method: Septic System Density

Min Acres/System
- N/A
- 2
- 2.2
- 2.3
- 2.4

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The GIS Center at Stony Brook
December 2003

Data Sources:
NJGS Nitrate Dilution Model v5.0
Roads, Municipal Boundary: Montgomery Twp
Figure 5: Aquifer Recharge Rates

Aquifer Recharge
- 2.2 in/yr
- 5.5 in/yr
- Faults
- Roads
- Streams

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The GIS Center at Stony Brook
December 2003

Data Sources:
Geology: NJ Geologic Survey CD 00-1
Roads, Municipal Boundary: Montgomery Twp
Figure 6:
Aquifer Recharge Method
Septic System Density

Data Sources:
Geology: NJ Geologic Survey CD 00-1
Rocks, Municipal Boundary: Montgomery Twp

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The GIS Center at Stony Brook
December 2003