# Estimating Soil and Groundwater Attenuation Factors for Nitrogen from Onsite Wastewater Systems in the Chesapeake Bay TMDL

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**Abstract.** An expert panel has been tasked with estimating the percent of N and P lost between the onsite wastewater treatment system (OWTS) drainfields and surface waters as part of the Chesapeake Bay Total Maximum Daily Load (TMDL). We used data from a recent study in Gwinnett County, Georgia, to estimate groundwater attenuation factors which could be used for the Piedmont region of the Chesapeake Bay watershed. In 12 small suburban streams with an average area of 2.01 km$^2$, we used baseflow measurements of total nitrogen (TN) load and we estimated N input to groundwater from OWTS as well as atmospheric deposition, lawn fertilization, and fertilization of hay/pasture. To calculate the groundwater attenuation factor, we subtracted the ratio of the TN load in the stream (output) and the TN from the various sources reaching groundwater (output) from 1. We did the same analysis for a larger (44.60 km$^2$) watershed on Big Haynes Creek for comparison. The groundwater attenuation factors for the 12 small streams ranged from 74 to 92% with an overall average of 86%. The groundwater attenuation factor for Big Haynes Creek was slightly lower, 81%, primarily due to higher baseflow yield which may indicate that the smaller watersheds do not represent a complete water balance.

## INTRODUCTION

The Chesapeake Bay Total Maximum Daily Load (TMDL), developed in 2010, sets allocations for the amount of nitrogen (N) and phosphorus (P) that the Bay can receive while meeting water quality standards. Onsite wastewater systems (OWTS) or septic systems were estimated to contribute about 4.5% of the N load to the Bay (Tetra Tech, 2011). An expert review panel convened by Tetra Tech in 2012 estimated that a conventional OWTS discharged 5 kg total nitrogen (TN) per capita per year based on a typical septic tank effluent TN concentration of 60 mg/L and a flow rate of 227 L (60 gals) per capita per day. The panel concluded that a 20% reduction in TN could be expected in the OWTS drainfield so that the loading to groundwater would be 4 kg TN/person/year (Tetra Tech, 2014).

A new expert panel was convened by Tetra Tech in late 2014 to estimate the percent of N and P lost between the OWTS drainfield and third order streams which are the smallest streams contained in the computer models used to calculate nutrient loading to the Bay. We will refer to the percent reduction in the drainfield as a soil attenuation factor and the reduction between the drainfield and the receiving water body as a groundwater attenuation factor. The current assumptions in the models are that the soil attenuation factor is 20% and the groundwater attenuation factor is 60%, for an overall attenuation factor of 68%. The panel has been asked to refine these values and see if different values for major physiographic regions in the Chesapeake Bay watershed are appropriate by the summer of 2015. The first author is a member of the new panel.

Valiela et al. (1997 and 2000) developed a N loading model for the 37.9 km$^2$ Waquoit Bay on Cape Cod in Massachusetts. The model included N inputs from atmospheric deposition, OWTS, and fertilizers (Fig. 1). For OWTS N, a 6% reduction in the septic tank, a 35% reduction in the drainfield, and a 34% reduction in the OWTS groundwater plume, based on data from Robertson et al. (1991) and Robertson and Cherry (1992), were assumed. For atmospheric sources of N (wet and dry deposition), it was assumed that 0% was lost to volatilization from impervious surfaces, 62% was lost to volatilization in lawns and in agriculture, and 65% was lost to volatilization in forests. For fertilizers applied to lawns and agriculture, it was assumed that 39% was lost to volatilization. For impervious surface runoff, lawns, agriculture, and forests, another 61% was lost in the soil (vadose zone). In the groundwater for all these sources, a 35% reduction was assumed.

In North Carolina, the On-site Water Protection Branch estimated attenuation rates for OWTS in Falls Lake watershed streams in the Piedmont physiographic region (NCDENR, 2009; Berkowitz, 2013). The study conservatively assumed that the entire in-stream load of N under base flow conditions was a result of septic system inputs via groundwater recharge. They estimated the N input from OWTS on a daily basis and compared that to measurements of instantaneous stream load under baseflow conditions at United States Geological Survey (USGS) gage stations. The overall attenuation factor (soil and groundwater) was 96% for TN. Tetra Tech conducted a similar analysis of USGS baseflow daily load data from a stream in the Jordan Lake watershed which is also in the Piedmont region and estimated an overall attenuation factors of 92% for TN. Berkowitz (2013) described a study that measured instantaneous loads in three streams near Durham NC at monthly intervals for one year (9 baseflow conditions and 3 stormflow conditions). The average overall attenuation factor was 96% for TN.

In a recent study, we measured flow and TN concentrations under baseflow conditions in 24 first-order streams in Gwinnett County in the Piedmont region of Georgia (Oliver et al., 2014). These are the same watersheds that were analyzed in a USGS study by Landers and Ankorn (2008). In this article, we report on the groundwater attenuation factors we calculated using this data and a larger watershed with a USGS gage data in the same area.

## MATERIALS AND METHODS

The streams in the study by Oliver et al. (2014) were selected to represent a range in OWTS density. We divided the 24 streams into two groups of 12 streams: streams with OWTS density less than an arbitrary cut-off of 39 OWTS/km$^2$ (100 OWTS/mile$^2$) were considered low density and streams with OWTS density above the cut-off were considered high density. The low density watersheds were more rural and contained more agriculture than the high density watersheds. In this paper for the purpose of calculating OWTS attenuation factors, we only considered the 12 high density watersheds. This was done to minimize the effect of agricultural sources of N.

The 12 high density watersheds are listed in Table 1 and shown in Fig 2. They ranged in area from 0.18 to 3.29 km$^2$ with an average area of 2.01 km$^2$. Note that the stream number is preserved from the study by Oliver et al. (2014) and that stream # 15 was a low density watershed (missing from Table 1). OWTS density ranged from 88 to 397 with an average of 218 systems/km$^2$. Land use was based on the National Land Cover Dataset for 2001. Urban landuse in Table 1 was calculated as the sum of low, medium, and high density residential plus industrial landuse. Hay/pasture landuse was calculated as the sum of hay and range-grasses landuse. There were no known point sources of N or inflow such as wastewater treatment plants in the watersheds.

In our study, synoptic sampling and flow measurements were taken three times per year for three years to capture the seasonal flow variations. All measurements were taken under baseflow conditions within a 24-hour period with no intervening rainfall. Measurements and sampling events occurred in November of 2011; March, July, and November of 2012; April, July, and November of 2013; and March and July of 2014. Methods for measuring stream flow and analyzing the samples for ammonium, nitrate, and total Kjeldahl N are described in Oliver et al. (2014).

To calculate attenuation factors, we estimated N input to groundwater from OWTS as well as atmospheric deposition, lawn fertilization, and fertilization of hay/pasture using the values from Valiela (1997 and 2000). We assumed that OWTS average discharge per home was 666 L/day based on data from the Gwinnett County Government (Gwinnett County, 2013). We also assumed that average the number of persons per household was 3.07 based on census data from Gwinnett County for 2007-2011 (Gwinnett County, 2015). This resulted in a per capita OWTS discharge of 221.3 L/day (58 gals per day). We assumed that the TN concentration of the septic tank effluent was 60 mg/L, which is the median value in a review by McCray et al. (2005) of OWTS effluent characteristics. We also assumed that 50% of the N was lost in the septic tank and drainfield due to denitrification/volatilization based on a field study we did in a Piedmont soil (Bradshaw et al., 2014). This value is higher than the combined effect of the septic tank and drainfield losses (40%) in Valiela et al. (1997 and 2000), but that is expected for the clayey soils of the Piedmont region. We did not include the OWTS plume reduction factor of 34% (see Fig. 1) from Valiela et al. (1997 and 2000) because we were not convinced that the groundwater beneath an OWTS drainfield would have higher denitrification rates than groundwater beneath other landuses.

For hay/pasture landuse, we assumed that these fields were fertilized with poultry litter (a common practice in this area) at an average rate of 1,600 kg/ha and that the litter contained 3.7% TN. To arrive at the application rate, we calculated the amount of litter produced in the county by multiplying the number of broilers produced in the county in 2007 (GADNR, 2007) by average litter

Table 1:

| Stream # or Name | Area km$^2$ | Density OWTS/km$^2$ | Urban % | Hay/Pasture % | Baseflow Yield m/year | TN mg/L | Attenuation % |
|---|---|---|---|---|---|---|---|
| 12 | 3.29 | 115 | 52.9 | 10.3 | 28.5 | 1.58 | 83 |
| 13 | 8.81 | 88 | 59 | 10.4 | 20.8 | 1.16 | 91 |
| 14 | 1.74 | 141 | 62.5 | 11.2 | 27 | 1.72 | 85 |
| 16 | 2.59 | 188 | 69.8 | 0.3 | 15.6 | 2.3 | 90 |
| 17 | 1.68 | 228 | 67.5 | 7.3 | 24.2 | 2.73 | 84 |
| 18 | 0.98 | 307 | 69.3 | 1.3 | 25.4 | 3.63 | 79 |
| 19 | 0.18 | 397 | 74.4 | 0.0 | 32 | 3.97 | 75 |
| 20 | 0.54 | 292 | 71.8 | 0.0 | 13.4 | 2.54 | 92 |
| 21 | 1.14 | 216 | 64.3 | 3.9 | 16.9 | 1.68 | 92 |
| 22 | 1.94 | 156 | 72.9 | 3.8 | 17.3 | 1.66 | 91 |
| 23 | 0.52 | 232 | 75.5 | 3.3 | 14.7 | 2.38 | 91 |
| 24 | 0.67 | 256 | 75.5 | 2.8 | 21.8 | 2.81 | 86 |
| **Average** | **2.01** | **218** | **68** | **4.6** | **21.5** | **2.35** | **87** |
| Big Haynes | 44.6 | 88 | 58.3 | 10.3 | 37.7 | 1.43 | 82 |

production per broiler and dividing by the total area in hay/pasture. The rate of 1.6 Mg/ha is lower than the minimum typically applied (3 tons/acre or about 3 Mg/ha) so it is likely that some of the fields do not receive litter. The TN content was based on a study by Qafoku et al. (2001) that analyzed 62 broiler litter samples for their TN content. Following Valiela et al. (1997 and 200), we assumed that 39% of the N applied was lost to volatilization and 61% of the remaining N was lost in the vadose zone due to denitrification so that 24% of the TN applied as litter reached the groundwater.

For urban landuse, we assumed an average annual application rate of lawn fertilizer of 120 kg N kg/ha based on a study by Osmond and Hardy (2013) on lawn practices in North Carolina. This study showed that 70% of homeowners applied fertilizer to lawns. The recommended rate for bermudagrass in Georgia is 170 kg/ha and 70% of that figure is approximately 120 kg/ha. Following Valiela et al. (1997 and 2000), we assumed that 39% of the N applied was lost to volatilization and 61% of the remaining N was lost in the vadose zone due to denitrification so that 24% of the TN applied as litter reached the groundwater. Using the same assumptions for volatilization and denitrification as hay/pasture, we assumed that 24% of the TN applied as lawn fertilizer reached the groundwater. For atmospheric sources of N, we assumed that the TN concentration in precipitation was 0.99 mg/L and that the dry deposition rate for TN was 0.76 kg/ha based on the Clean Air Status and Trends Network (CASTNET, 2015) data for Georgia. We assumed an annual precipitation rate of 121 cm based on the 3-year average for 2012-2014 in Athens, GA (NOAA, 2015). We assumed that all landuse received atmospheric N and used the loss percentages from Valiela et al. (1997 and 2000) (62% for volatilization and 61% in the vadose zone) so that 14% of the atmospheric N input reached groundwater.

To calculate the groundwater attenuation factor ($af$) we subtracted the ratio of the TN load in the stream (output) and the TN from the various sources reaching groundwater (output) from 1 and expressed $af$ as a percentage:

$$af = 1 - \frac{N_{stream}}{N_{OWTS} + N_{lawn} + N_{hay/pasture} + N_{atmospheric}} \tag{1}$$

where N$_{stream}$ was the measured average baseflow TN in each stream, N$_{OWTS}$ was the estimated input of TN to groundwater from OWTS, N$_{lawn}$ was the estimated input of TN to groundwater from lawn fertilization, N$_{hay/pasture}$ was the estimated input of TN to groundwater from hay/pasture fertilization, and N$_{atmosphere}$ was the estimated input of TN to groundwater from atmospheric deposition, all in units of kg/day.

To provide a comparison with a larger watershed, we also calculated attenuation factors for Big Haynes Creek on the watershed defined by the USGS gage station near Lenora Road near Snellville in Gwinnet County (station number 02207385). Continuous flow data was available for this site and total N concentrations were measured on 49 dates from 3/12/1996 to 6/23/2008. Flow on these dates ranged from 0.10 to 202.78 m$^3$/s. We used a base flow separation program (Arnold et al., 1995) to determine dates when flow was no greater than 150% of the base flow value. There were 16 dates during the period 2/5/2005 to 6/23/2008. We used the same assumptions about sources of N as in the 12 small streams to calculate an average groundwater attenuation factor for these dates.

## RESULTS

The average baseflow yield for the nine synoptic sampling dates in the 12 small watersheds ranged from 13.4 to 32.0 m/year with an overall average of 21.5 m/year. Total N concentrations averaged over sampling dates ranged 1.16 to 3.97 mg/L with an overall average of 2.35 mg/L. Oliver et al. (2014) showed that TN concentrations increased linearly with OWTS density in these streams. The groundwater attenuation factors calculated using Equation 1 ranged from 74 to 92% with an overall average of 87%. There was no apparent relationship between attenuation factor and OWTS density, watershed area, or baseflow in the small streams. Our groundwater attenuation factor is considerably higher than the value of 35% estimated in Valiela et al. (1997 and 2000). Those authors included an attenuation factor for the OWTS plume of 34% and the combined attenuation factor (plume plus groundwater) was 57% which is still considerably less than our value of 87%. A higher value for the Piedmont region is expected due to longer travel times compared to the Cape Cod sand and gravel aquifer (Cambareri and Eichner, 1998; Rose, 1992).

Our approach assumes that the average baseflow load approximates the total groundwater load to streams. During storms, the groundwater component of the hydrograph increases slightly due to interflow and a slow rise in baseflow (Fetter, 1988). Storm samples that we have collected on two of the twelve streams in this report show that nitrate concentrations remain constant or decrease during most storms. Organic N concentrations increase substantially during storms, but we assume that that is due to runoff. Ammonium concentrations remain low. As such, the groundwater TN load during storms is only slightly higher than during baseflow. Our baseflow approach may slightly underestimate the total load due to any increase in the groundwater component during storms. This would lead to an underestimation of the stream load and an overestimation of the groundwater attenuation factor.

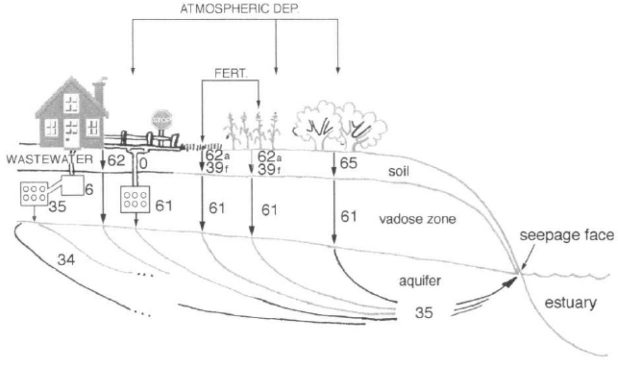

Figure 1:

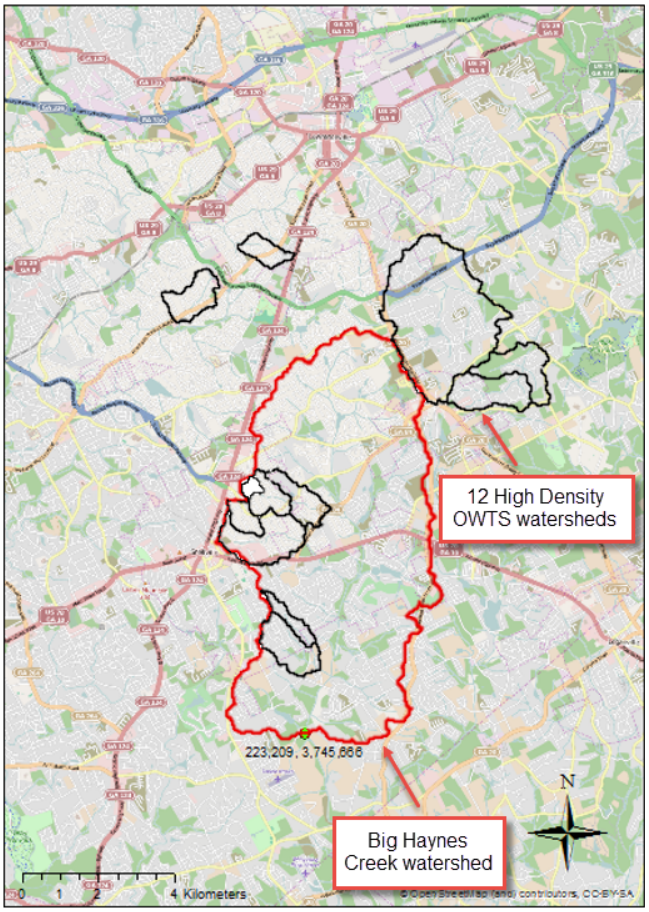

Figure 2:

If we combine the 50% soil attenuation factor we assumed with the average groundwater attenuation factor of 87%, the overall attenuation factor (soil and groundwater) is 94% which is similar to the values calculated in the NC studies (92-96%). By comparison, Mines et al. (2014) in a study of five large waste water treatment facilities (16 to 120 million gals per day permitted capacity) near Atlanta found that the reduction in TN using input and output concentrations varied from 79 to 100%.

For the Big Haynes Creek watershed, the estimated groundwater attenuation factor was 82%, slightly lower than the average value for the 12 small streams (Table 1). The TN concentration in the Big Haynes Creek samples (1.43 mg/L) was lower than the average for the 12 small streams (2.35 mg/L). However, stream 13 had the identical OWTS density to Big Haynes Creek and the concentration in that stream was 1.16 mg/L. The main difference between the small streams and Big Haynes Creek, and the reason for the difference in attenuation factors, is the higher average baseflow yield of 37.7 m/year in Big Haynes Creek compared to 21.5 m/year for the small streams. The higher baseflow resulted in more output of TN and a lower attenuation factor.

This raises the possibility that using streams to calculate attenuation factors may underestimate the attenuation factor if the watersheds are too small to represent an accurate water balance. It may be that a significant fraction of groundwater flow occurs below the stream bed in the small watersheds and they do not represent a complete water balance. However, the difference between the small and large watersheds was small.

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