

**NITROGEN AND PHOSPHOROUS MIGRATION AND ATTENUATION  
ASSESSMENT FROM SUBSURFACE WASTEWATER TREATMENT  
SYSTEMS**

## **Introduction**

This document presents a summary of the factors affecting migration and attenuation of nitrogen and phosphorus after disposal from subsurface wastewater treatment systems (aka septic systems). The summary is used to support methods proposed for determining numerical values for nitrogen and phosphorus reduction as they migrate towards surface waters. This process is based upon on peer-reviewed scientific papers, case-studies, and methods used in other states.

The methods described in the document should not be used to determine nutrient attenuation on a small scale (e.g. single development/municipality discharge) due to the potentially wide variation in nutrient attenuation between sources in similar settings. These methods are designed for use on a larger basin-wide scale that effectively allows averaging of the wide variation of processes that occur in the subsurface between wastewater discharge in the vadose zone and subsequent migration into the surface water.

While the methods of nutrient attenuation described in this document are well documented and generally accepted in the scientific community, the attenuation percentages proposed in this methodology are estimates. When these estimated values are used they should be compared with other available data and adjusted if necessary to reflect more accurate or other site specific data.

## **NITROGEN**

Nitrogen in untreated domestic wastewater (in the septic tank) is primarily in the form of ammonia. Disposal of wastewater in a properly constructed and sized drainfield will typically provide sufficient oxygen and naturally occurring bacteria to convert the ammonia to nitrite and then quickly to nitrate. It is a common assumption in studies and regulations that most or all the nitrogen is converted to nitrate after proper septic tank and drainfield (conventional) treatment (NDWRCDP, July 2005; Heatwole and McCray, 2006; Idaho Department of Environmental Quality, 2002; Montana DEQ, 2009; Morgan et. al., 2007). Unless an advanced wastewater system is used (referred to as a level 2 system in Montana), conventional treatment only removes between 10 and 30 percent of the nitrogen in the wastewater (Seabloom, 2004; Gold and Sims, 2000; Pell and Nyberg, 1989; Laak, 1981; Costa et. al., 2002; Rosen et. al., 2006; and Lowe et. al., 2007). That reduction is accounted for in the nitrogen concentration (50 mg/L) that Montana estimates is discharged from the average conventional septic system serving a single-family home. The final step of the wastewater nitrogen cycle is conversion of nitrate to nitrogen gas (denitrification), which then off-gasses and does not have any further impacts to groundwater or surface water. The denitrification step is the most difficult part of the nitrogen cycle to predict.

In Montana, the nitrate loading rate for a single-family home septic system is based on average concentration and loading data of 50 mg/L and 200 gallons per day of effluent. Those values provide a loading rate of 30.5 lbs/year for a conventional wastewater system. For comparison purposes, the loading rate for a level 2 system is 14.6 lbs/year.

Denitrification requires the correct environment to occur. Although there are other factors, the key ingredients are adequate temperature (typically above 10 °C), a food source for the bacteria (typically carbon), an anoxic environment (generally an O<sub>2</sub> range of less than 1-2 mg/L), and the correct bacteria. A carbon source is cited as the most common limiting factor for denitrification (Gold and Sims, 2000; Kobus and Kinzelbach, 1989; Rivett et. al., 2008;). Studies refer to an environment that commonly has these four characteristics – riparian environments with shallow ground water (Gold and Sims, 2000; Rosenblatt, et. al., 2001; Gilliam, 1994; Harden and Spruill, 2008; McDowell et. al., 2005). Studies have identified “micro-sites” of low oxygen in shallow ground waters that are typically assumed to be rich in oxygen to provide the necessary anoxic environment (Parkin, 1987; Jacinthe et. al., 1998; Gold and Sims, 2000). The correct bacteria are generally ubiquitous in the environment and will naturally thrive when the conditions are correct and there is a nitrogen source in the ground water. However, it should be noted that the USEPA (2002) stated that “Denitrification has been found to be significant in the saturated zone only in rare instances where carbon or sulfur deposits are present”. This conclusion is contrary to the numerous studies that have found high denitrification rates in common environments; the same USEPA document recognizes some of those studies.

Typically, fine-grained soils provide better conditions for denitrification than coarse-grained soils (Umari et al., 1995; Tesoriero and Voss, 1997; Briar and Dutton, 1999; and Mueller et al., 1995). Fine-grained soils are more likely to contain two of the conditions necessary for denitrification: anoxic conditions and carbon. Anderson (1998) used results from several studies to show a correlation ( $r=0.91$ ) between denitrification rates and soil organic content. One study (Ricker et al., 1994) estimated the amount of denitrification beneath drainfields as 15% for sandy soils and 25% for other finer soils.

Studies indicate that denitrification rates are site-specific and the rates can vary considerably in similar environments (Robertson et al., 1991; and Starr and Gillham, 1993). Some studies have provided measurable chemical characteristics to determine where denitrification is more likely to occur (Trojan et. al. 2002; Minnesota Pollution Control Agency, 1999), but the studies typically only provide relative denitrification rates (e.g. high or low). However, several recent studies (Kirkland, 2001; NDWRCDP, January 2005; and McCray et. al., 2005), have published a specific denitrification rate based on cumulative frequency distributions of published field measured denitrification rates ( $0.025 \text{ day}^{-1}$ ). At that rate, it takes about 11 years to denitrify all the nitrate from a source. Eleven years of travel may require between 400 and 40,000 feet of migration distance at typical ground water velocity rates of 0.1 to 10 ft/day. Using a single value for denitrification rates may be overly simplistic as one study indicated it would take a denitrification rate that ranges over 3 orders of magnitude to provide a 95% confidence interval (Heatwole and McCray, 2006).

Regulations in other states regarding nitrate attenuation sometimes assume the amount of denitrification increases with the distance between the source and the surface water. The distance also correlates to the ground water age since it was discharged. This distance/age criterion is based on studies showing that denitrification increases with the length of time it takes wastewater to migrate to surface water: the longer the nitrate is in the environment the more time the nitrate has to encounter the correct conditions for denitrification (Kroegger et. al. 2006). Increasing well depth, which is correlated to the age of the ground water, has also been

correlated to decreasing nitrate concentrations in ground water (Briar and Dutton, 1999; Thomas, 2000; Bonn et al., 1995; Spalding et al., 1993; Tesoriero and Voss, 1997; Boer, 2002; Verstraeten et al., 1998; and Mitchell et al., 2003). The ground water age and denitrification correlation likely becomes more accurate as the scale of the application increases (i.e. more accurate for a basin wide analysis versus analysis of a specific development), but may not be the most defensible method of predicting nitrate attenuation (Gold and Sims, 2000). The distance criteria may be used more frequently as compared to travel time because it is easier to measure distances than it is travel time which requires three parameters in the saturated zone: hydraulic gradient, hydraulic conductivity and effective porosity.

Based on the above summary two methods are described below for estimating nitrogen loading to surface waters from septic systems.

- Use existing data to determine average hydraulic conductivity, hydraulic gradient and effective porosity for each basin to determine estimated travel rates in a basin. Using the calculated travel rate(s) and the “universal” denitrification rate of  $0.025 \text{ day}^{-1}$  described above to estimate loading values for ranges of travel times to surface water. For example, separate the loading amounts into distance ranges of 0-100 feet, 100-500 feet, 500-5,000 feet, 5,000-20,000 feet and 20,000+ feet. Each septic system in those distance ranges would be assigned the same nitrogen loading rate (a percentage of the total loading discharged at the drainfield) to the surface water. Travel time to tributaries may complicate the issue if they are gaining streams.
- The second method is a matrix (see attached table 1) that combines four factors that impact the amount of denitrification: soil type beneath the drainfield; soil type in the riparian area; distance to surface water; and depth to ground water. In the table each drainfield is assigned a percent denitrification factor for each of the four criteria. The percentages assigned for each column are then added to provide the total percent nitrate removal for that septic system. The nitrate loading rate (30.5 lbs/year for a conventional system) to the surface water is then reduced accordingly. Any system with a percent reduction of 100% or more is assumed to contribute no nitrate to the surface water. Depending on the data available for a particular basin, the individual columns in the table can be removed if adequate data for that criterion is not available. Also, average values of soil types across sub-basins (or the entire basin) can be calculated and used for groups of septic systems rather than assigning each septic system or riparian area a specific value.

Both of the above methods assume steady-state conditions exist for estimating phosphorus loading to surface water in that they do not account for the time needed for the phosphorus load from a new discharge source to migrate towards the receiving surface water. That lag time is dependent on the distance to the receiving water and the travel rate through both the vadose and saturated zones.

Failing septs could be accounted for by increasing their loading amounts relative to properly operating septs (wastewater from a failing system is assumed to runoff as overland flow or flow near the surface). Estimating the percent of failing systems is difficult, one method is to base the failure rate on the soil type (failure rate increasing as soil permeability decreases). But,

the amount of hydraulically failing systems where the wastewater is flowing at the surface is likely a relatively small percentage of the total number of septic systems on a basin wide scale and is likely not a significant nutrient load for TMDL purposes. At a more local level in a small basin for example, there may be situations where failing septic systems are a significant source and need to be accounted for.

**Table 1 – Nitrogen Attenuation Factors for Septic System Discharges to Ground Water**

<b>Percent Nitrogen Load Reduction<sup>(1)</sup></b>	<b>Soil Type @ Drainfield<sup>(2)</sup></b>	<b>Soil Type within 100' of surface water<sup>(2)</sup></b>	<b>Distance to surface water (ft)</b>	<b>Groundwater Depth @ drainfield<sup>(3)</sup></b>
0	A	A	0 – 100	
10	B		101 – 500	<200 cm
20	C	B	501 – 5,000	
30	D	C	5,001 – 20,000	
50		D	20,001+	

Notes:

(1) The total nitrogen reduction is the sum of the individual reductions for each column of the table. For example a drainfield that is in a type C soil (20%) that drains to a surface water with type B soil (20%) and is 200 feet from the surface water (10%) and has shallow water greater than 200 cm (0%) would reduce their nitrogen load to the surface water by 50% from what is discharged from the drainfield.

(2) Soil descriptions are available via the NRCS web soil survey at:

<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> . Once the area of interest (AOI) has been defined information is accessed by clicking on following links: “Soil Data Explorer” – “Soil Properties and Qualities” -- “Soil Qualities and Features” – “Drainage Class”. The NRCS soil survey has seven soil drainage classes that are correlated to the A, B, C and D designation in the table as follows:

A = excessively drained or somewhat excessively drained

B = well drained or moderately well drained

C = somewhat poorly drained

D = poorly drained or very poorly drained

Within the defined area of interest, the soil survey application provides the percent of soil types with these attributes. That feature provides a quick way to determine the percent of each soil type and therefore the percent reduction for each area of interest defined.

(3) Depth to ground water is available via the NRCS web soil survey at:

<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> . Once the area of interest has been defined information is accessed by clicking on following links: “Soil Data Explorer” – “Soil Properties and Qualities” -- “Water Features” – “Depth to Water Table”. Within the defined area of interest, the soil survey application provides the percent of land with the appropriate depth to ground water. That feature provides a quick way to determine the percent of area where ground water is less than or greater than 200 cm and therefore the percent reduction for each area of interest defined.

## PHOSPHORUS

Phosphorus is immobilized below drainfields by two primary processes, adsorption and precipitation. Precipitation is a slower process compared to adsorption but may be the more important process for retarding the migration of phosphorus. Phosphorus that is adsorbed can be desorbed at a later time, but precipitated phosphorus is typically immobilized permanently. Phosphorus is much less mobile than nitrogen once discharged from a drainfield. The vadose zone is considered the primary location for phosphorus retardation, once it reaches groundwater phosphorus migration is generally faster than in the vadose zone.

Published information indicates that non-calcareous soils retard the movement of phosphorus much more than calcareous soils (typically non-calcareous soils are derived from igneous or metamorphic parent rocks) due to the calcareous soils ability to maintain pH levels where phosphorus precipitation does not readily occur (Robertson et. al., 1998; Lombardo, 2006). Lombardo (2006) defined calcareous soils as those containing more than 15% calcium carbonate equivalent and non-calcareous soils as those containing less than 1 % calcium carbonate. Finer-grained soils also tend to retard phosphorus migration more than coarser soils due primarily to their greater surface area.

Studies suggest that wastewater phosphorus plumes extend a relatively short distance from the source (Makepeace and Mladenich, 1996; Robertson et. al., 1998; Gold and Sims, 2000; Reneau et. al., 1989). Studies have found high concentrations of phosphorus in soils immediately below drainfields with low levels beyond that location (Robertson et. al., 1998; Lombardo, 2006; Gold and Sims, 2000). This indicates that a significant portion of the phosphorus is quickly bound up shortly after being discharged. However, some of these studies did not use low level phosphorus detection limits and may have underestimated the migration length of low concentration phosphorus plumes (Houston, 2004). Some studies indicate that soils have a limited amount of absorption and precipitation capacity before reaching equilibrium and allowing further migration of phosphorus (Gold and Sims, 2000). Lombardo (2006) estimated that phosphorus travel times to nearby surface waters could range from tens of years to hundreds of years depending on the types of soils between the source and water body.

The MANAGE nutrient migration model (Kellogg et. al., 2006) ignores phosphorus discharges from drainfields except from failing drainfields. Other information (NDWRCDP, June 2005; Gold and Sims, 2000; McDowell et. al., 2005) also implicates failing or improperly sited (i.e. drainfields located over shallow ground water, in coarse soils, or too close to surface water) drainfields as a much greater threat to surface water than properly constructed and sited systems.

Lombardo (2006) suggested that phosphorus migration to surface waters is only a problem in areas with high groundwater tables and higher groundwater velocities (the report provided a lower end for the high velocities of approximately 0.2 to 3 feet/day). Below that velocity soils typically contain higher amounts of clay and/or silt.

One option for assessing phosphorus contributions to surface water is to use a sorption isotherm to predict the retardation of P in the subsurface. However, a sorption isotherm does not account for precipitation reactions that may significantly effect P migration (USEPA, 2002). Precipitation reactions and rates are soil characteristic specific and therefore require more site-specific information to predict (McCray et. al., 2005; Gold and Sims, 2000).

Outside of failing or poorly sited septic systems, existing evidence indicates that only small amounts of phosphorus do migrate to surface waters, but that in some cases even small amounts can have noticeable impacts to surface water quality.

Based on the above summary two methods are described below for estimating phosphorus loading to surface waters from septic systems.

- Assume no phosphorus loading for all systems unless they are hydraulically failing or within 100 feet of the surface water
- The second method is a matrix, similar to the one used for nitrate, (see attached **table 2**) that combines three factors that have been shown to impact the amount of denitrification: soil type beneath the drainfield; calcium carbonate percent in the soil; and distance to surface water. In the table each drainfield is assigned a percent phosphorus reduction for only one of the first three columns (the soil and calcium carbonate type), and then an additional percent phosphorus reduction for the fourth column (distance to surface water). The percentages assigned for each column are then added to provide the total percent phosphorus removal for that septic system. The phosphorus loading rate (6.44 lbs/year for a conventional or level 2 system) to the surface water is then reduced accordingly. Any system with a percent reduction of 100% or more is assumed to contribute no phosphorus to the surface water. Depending on the data available for a particular basin, the individual columns in the table can be removed if adequate data for that criterion is not available. Also, average values of soil types across sub-basins (or the entire basin) can be calculated and used for groups of septic systems rather than assigning each septic system a specific value.

Both of the above methods assume steady-state conditions exist for estimating phosphorus loading to surface water in that they do not account for the time needed for the phosphorus load from a new discharge source to migrate towards the receiving surface water. That lag time is dependent on the distance to the receiving water and the travel rate through both the vadose and saturated zones.

**Table 2 - Phosphorus Attenuation Factors for Septic System Discharges to Ground Water**

<b>Percent Phosphorus Load Reduction<sup>(1)</sup></b>	<b>Soil Type @ Drainfield<sup>(2, 3)</sup> (CaCO<sub>3</sub> ≤ 1%)</b>	<b>Soil Type @ Drainfield<sup>(2, 3)</sup> (CaCO<sub>3</sub> &gt;1% and &lt;15%)</b>	<b>Soil Type @ Drainfield<sup>(2, 3)</sup> (CaCO<sub>3</sub> ≥15%)</b>	<b>Distance to surface water (ft)</b>
0	A	A	A	0 – 100
10			B	
20		B	C	
30	B		D	101 - 500
40		C		
60	C	D		501 - 5,000
90	D			
100				5,001 +

**Notes:**

(1) The total phosphorus reduction is the sum of the individual reductions for the soil type (only use one of the three soil columns) and the distance to surface water. For example a drainfield that is in a type B soil with less than 1% CaCO<sub>3</sub> (30%) and is 200 feet from the surface water (40%) would reduce their nitrogen load to the surface water by 70% from what is discharged from the drainfield.

(2) Soil descriptions are available via the NRCS web soil survey at:

<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> . Once the area of interest (AOI) has been defined information is accessed by clicking on following links: “Soil Data Explorer” – “Soil Properties and Qualities” -- “Soil Qualities and Features” – “Drainage Class”. The NRCS soil survey has seven soil drainage classes that are correlated to the A, B, C and D designation in the table as follows:

A = excessively drained or somewhat excessively drained

B = well drained or moderately well drained

C = somewhat poorly drained

D = poorly drained or very poorly drained

Within the defined area of interest, the soil survey application provides the percent of soil types with these attributes. That feature provides a quick way to determine the percent of each soil type and therefore the percent reduction for each area of interest defined.

(3) CaCO<sub>3</sub> percent is available via the NRCS web soil survey at:

<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx> . Once the area of interest has been defined information is accessed by clicking on following links: “Soil Data Explorer” – “Soil Properties and Qualities” -- “Soil Chemical Properties” – “Calcium Carbonate (CaCO<sub>3</sub>)”. Within the defined area of interest, the soil survey application provides the percent of land with the percent of CaCO<sub>3</sub>. That feature provides a quick way to determine the percent of area of different CaCO<sub>3</sub> percentages and therefore the percent reduction for each area of interest defined.



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