Response to Charge Questions on the Nitrate Dilution Model

Summary Report
of the NJDEP Science Advisory Board

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INTRODUCTION AND SUMMARY OF CONCLUSIONS

The Nitrate Dilution Model is a regulatory planning tool used to limit residential development density in unsewered areas. Wastewater from such residences is usually treated by septic systems. Table 1 summarizes the model, including its major assumptions. The NJDEP charged the Water Quality and Quantity Committee (WQQC, a standing committee of the NJDEP Science Advisory Board) with questions to evaluate the assumptions and applicability of the NDM. The Science Advisory Board (SAB) based this report on recommendations from the WQQC. The most significant responses could be summarized as follows:

- The assumptions of the Nitrate Dilution Model (NDM) are appropriate for protecting groundwater from nitrate originating in residential septic systems
- The NDM is not appropriate for near-field applications (protection of individual wells)
- The NDM is not appropriate for protection of surface water except in certain local situations where the surface water quality is closely coupled to groundwater
- Nitrate is not suitable as a surrogate for other pollutants transmitted from sanitary waste to surface water via septic systems.
- The NDM has potential for assessing the potential for impacts from pollutants that pass unmediated from septic systems to the groundwater

The NJDEP Charge Questions and associated findings of the Water Quality and Quantity Standing Committee of the New Jersey Science Advisory Board are as follows:

1A. Please comment on the appropriateness of the assumptions made by the nitrate dilution model. Are these assumptions appropriate at the scale at which the model results are used for land-use planning decisions?

> **Finding:** The assumptions of the nitrate dilution model are appropriate for the purpose of estimating nitrate loading (rather than concentration) from subsurface wastewater disposal on downgradient groundwater quality. The model should not be applied to any individual lot.

1B. Are there sources other than septic systems (associated with development, e.g. landscaping) that should be included in the model?

> **Finding:** There are too many variables and uncertainties in other uses to include them a general nitrate-dilution model at this time. Such factors would require site-specific models.

2A. Please comment on the appropriateness of the assumption that nitrate in groundwater is unaffected as it moves from groundwater through the hyporheic zone into surface water.

> **Finding:** It is not appropriate to assume that nitrate in groundwater is unaffected as it moves from groundwater through the hyporheic zone into surface water. Nitrogen transformations in the hyporheic zone are well documented in the literature, especially denitrification. Overall, the issue is site specific and depends on geology, seasonality, stream-bottom sediments, and any biofilms in the stream sediments.

2B. What does the literature suggest is an appropriate nitrate standard to protect aquatic ecosystems.

> **Finding:** It would be difficult to try to define a groundwater nitrate concentration that would be protective of surface water ecology.

2C. Does this vary spatially or by receptor?

Finding: Yes, aquatic and marine environments vary significantly in their sensitivity to nitrogen.

3. What are the appropriate scales for applying the results of the nitrate dilution model?

3A. Near field – discharge from septic system to nearby well:

Finding: The dilution model discussed is not appropriate at this scale.

3B. Medium field – discharge from septic system to groundwater:

Finding: The medium field is appropriate for the dilution model discussed in this report.

3C. Far field – discharge from septic system to the bay or ocean:

Finding: The Nitrate Dilution Model is not appropriate for predicting impacts at this scale.

4. Is it appropriate to use the nitrate dilution model to predict the impact of nitrate coming from one or more septic systems at receptors all three of the spatial scales of concern? Is the current model adequate to be protective at all three scales? If not, at which scale is it most appropriate for and what are the preferred models to predict impacts at the other scales?

Response: The SAB merged this question with question 3 in the response to that question above.

5. Should the standard take into account prior land use and other nitrate sources?

Finding: Nitrate from prior land use is not likely to persist in the environment and does not need to be considered in estimating the nitrate impacts associated with a proposed new development. Control of other on-going nitrate sources should be done separately from the NDM.

6. Please comment on if it is appropriate to use elevated nitrate concentrations as a surrogate for other excessive anthropogenic impacts on water quality and the ecosystem.

Finding: The Nitrate Dilution Model has potential for assessing impacts from pollutants that pass unmediated to the groundwater. But this represents only the model for dilution and does not necessarily represent the overall impact of land use or potential nonhuman toxicity.

Table 1. Summary of the Nitrate Dilution Model & Application to Land-Use Planning

Overview	The nitrate dilution model (Hoffman and Canace, 2004) estimates the amount of pervious land needed to generate sufficient groundwater recharge to dilute the nitrate from a collection of Individual Subsurface Sewage Disposal Systems (ISSDSs or septic systems) to a nitrate standard. The application dilutes nitrate from the ISSDSs with on-site recharge. Off-site sources of nitrate and recharge are excluded. Other potential on-site nitrate sources are also excluded.
Intended Application	The model is designed to be applied at a regional planning scale to protect groundwater quality. It is not designed to predict nitrate concentrations in an individual well due to a nearby ISSDS.
Input Parameters	The model requires an estimate of average-annual nitrate loading from each ISSDS. This is based on the number of people per home and the annual per capita loading rate. This loading is diluted by groundwater recharge through pervious portions the land associated with the ISSDSs. The Hoffman and Canace (2004) version uses development-specific groundwater recharge estimates based on the method of Charles and others (1993). This requires data on soils and climate. The original formulation of this model (Trela and Douglas, 1978) used an average annual groundwater recharge estimate.
Equation	$A = 4.41\ P\ M\ /\ (R\ T)$ where: A = average pervious area per ISSDS (acres/home) M = nitrate loading rate (pounds of nitrate/person/year) P = per capita housing rate (# people/home) R = average groundwater recharge rate (inches/year) T = nitrate target concentration (mg-nitrate/l) 4.41 = conversion factor
Major Assumptions	• Nitrate is conservative and is not modified in the subsurface. • The nitrate from the ISSDS is fully mixed with on-site groundwater recharge. • No other on-site or upgradient nitrate sources. • Only on-site groundwater recharge is available to dilute the nitrate from the ISSDS. • The monitoring point is at a sufficient distance downgradient that temporal fluctuations in nitrate loading and groundwater recharge have averaged out.
Application	The nitrate dilution model is applied at a planning level to estimate average lot sizes. Actual lot sizes may vary from the average size.

BASES FOR THE FINDINGS

The NJDEP posed six questions concerning the NDM. Below are the six questions, each preceded by a background statement from the NJDEP, and followed by the response of the WQQC with a discussion of the basis for that response.

Question 1

Background: The nitrate dilution models current in use by NJDEP for regional land-use planning decisions are based on a number of assumptions. These include the conservative nature of nitrate in groundwater, complete mixing, and no other sources of nitrate other than that due to the installation of one or more ISSDSs.

1A. Please comment on the appropriateness of the assumptions made by the nitrate dilution model. Are these assumptions appropriate at the scale at which the model results are used for land-use planning decisions?

> **Finding:** The assumptions of the nitrate dilution model are appropriate for the purpose of estimating nitrate loading (rather than concentration) from subsurface wastewater disposal on downgradient groundwater quality. The model should not be applied to any individual lot .

Basis: The nitrate-dilution model (Hoffman and Canace, 2004) was developed to estimate nitrate impacts of subsurface disposal systems on groundwater. The model is a modification of an earlier mass-balance model of Trela and Douglas (1978) and incorporates the New Jersey Geological Survey's groundwater-recharge model (Charles et al., 1993). The model relies on several assumptions: First, all nitrogen loading ends up as nitrate in the groundwater, which is reasonable. Second, onsite recharge to groundwater is the only source of water diluting the effluent assumed in the model. The recharge is a principal variable that incorporates the effects of soil type and regional variation in precipitation. Model assumptions as to the average house occupancy rate (typically 3 persons) and per capita nitrate loading rate (10 lb annually) are also reasonable and may practically be considered as model constants. A target nitrate concentration in groundwater is the other major variable selected based on specific water quality goals of the user and on state regulations and policies designed to protect water quality. The target concentration may range from 1 to 3 mg/L nitrate for undeveloped area to 10 mg/L – the potable water standard for nitrate-nitrogen (Hoffman and Canace, 2004).

The assumptions that 1) onsite recharge is the sole water source available to dilute the wastewater, and that 2) complete and uniform mixing takes place at the water table, indicate that the model merely predicts an average nitrate concentration at the water table throughout the development area. The model does not consider large dilution effects by groundwater in storage beneath the site, or by lateral groundwater flow under ambient hydraulic gradient. Because of site-specific character of the latter dilution sources, their incorporation into this generic model would be difficult. There are few studies that could be used to determine the degree of mixing between shallow and deep groundwater, or of the fate of nitrogen in deeper groundwater, which may be very different in character from the shallow part of the aquifer (e.g., see Hill, 1991 and Ptacek, 1998). The exclusion of the dilution by groundwater makes the model a very conservative predictive tool. Comparison by Hoffman (2010; Table 22) of the actual nitrate concentrations in residential supply wells against the nitrate-dilution model-predicted concentrations indicates that the nitrate dilution model over-predicts actual average nitrate concentrations (derived from all sources) in residential supply wells by as much as 600% for developments in granular aquifers (the Cohansey of Presidential Lakes Estates) and 250% to 160% for large developments in the fractured bedrock setting (Vorhees Corner and Cherryville developments). Studies by Harman et al. (1996) of the plume from a long-established septic system in a sandy, unconfined aquifer show that N in septic waste was indeed oxidized to nitrate in the septic field and that the plume of elevated N concentration extend over 100 meters downgradient. Ptacek (1998) finds similar results.

The nitrate dilution model is an appropriate tool for the purpose of estimating nitrate loading (rather than concentration) from subsurface wastewater disposal on downgradient groundwater quality and for estimating impacts of onsite disposal on onsite supply wells. The model should not be applied to any individual lot but only on a larger scale. Septic systems and wells tend to be at similar distances apart regardless of lot sizes, so the assumption of complete and uniform mixing at the water table can hardly be satisfied at a given lot. Hydrogeologic heterogeneities, including the occurrence of preferential recharge and flow pathways at bedrock sites (Veccioli, 1967; Michalski and Britton, 1997), as well as of clay and gravel lenses at granular aquifer sites, may result in short-circuiting of wastewater flow into some residential wells and anomalously high nitrate levels in such wells. The model does not account for any such site-specific adverse impacts. These can be avoided, or minimized, through conducting a hydrogeologic site assessment to properly locate and construct the residential supply wells.

1B. Are there sources other than septic systems (associated with development, e.g. landscaping) that should be included in the model?

> **Finding:** There are too many variables and uncertainties in other uses to include them a general nitrate-dilution model at this time. Such factors would require site-specific models.

Basis: The use of nitrogen fertilizers, primarily on residential lawns, and the deposition of airborne nitrogen compounds (from coal and oil burning electric utilities and cars) are the two other major sources of nitrogen in residential developments. In the US, the latter source was estimated to contribute annually at least 3.2 million tons of nitrogen, which was approximately 28% of the 11.5 million tons of nitrogen applied as fertilizer in agricultural areas (Nolan et al., 1997). The airborne nitrogen may be a major contributor to background nitrate concentrations in groundwater throughout New Jersey. These ultimately affect water quality in estuaries, etc. Over 500,000 kg of N are added to Barnegat Bay annually (Hunchak-Kariouk and Nicholson, 2001 and Wieben and Baker, 2009).

Areas with high nitrogen input, well-drained soils and low woodland to cropland ratio have the highest potential for contaminating shallow groundwater by nitrate in the US (Nolan, 1997; Spalding and Exner, 1997). Studies from Long Island, NY (e.g. Bleifuss et al., 1998), and other regions (e.g. Bohlke and Denver, 1995) show that separation of impacts from the various nitrogen inputs (mineral and organic fertilizers, septic systems, and airborne sources) in groundwater would require extensive isotopic studies, which imposes practical limitations. There are too many variables and uncertainties in landscape fertilizer use to include it into the NJDEP's nitrate-dilution model at this time. Some homeowners do not fertilize their lawns, and only portions of larger lots are landscaped as lawns. With proper management practices, including the type of nitrogen fertilizer used, application rates, frequency and timing, applied nitrogen should not penetrate beyond the root zone. Change of land use from agricultural to residential may result in net decrease of nitrogen input. In cases of over-fertilized and over-watered lawns, surface runoff generally provides a more effective shallow migration pathway than groundwater. Geologic factors make South Jersey more vulnerable to nitrate impacts than North Jersey (e.g., Baker and Hunchak-Kariouk, 2005; Zampella et al., 2007).

Question 2

Background: Nitrate concentrations in groundwater are controlled to protect humans (NJDEP, 2009; NJDEP, 2010). The implicit assumption made in this application is that the current nitrate standards, which were developed to be protective of human health, are protective of the aquatic ecology. An additional assumption is that nitrate levels are unchanged as groundwater moves through the hyporheic zone into surface water.

2A. Please comment on the appropriateness of the assumption that nitrate in groundwater is unaffected as it moves from groundwater through the hyporheic zone into surface water.

> **Finding:** It is not appropriate to assume that nitrate in groundwater is unaffected as it moves from groundwater through the hyporheic zone into surface water. Nitrogen transformations in the hyporheic zone are well documented in the literature, especially denitrification. Overall, the issue is site specific and depends on geology, seasonality, stream-bottom sediments, and any biofilms in the stream sediments.

Basis: Literature amply supports the assumption that once in the saturated zone, nitrate "moves with the groundwater with no transformation and little or no retardation." (Freeze and Cherry, p. 413). This is particularly true in oxidizing environments such as shallow groundwater in highly permeable or fractured rock.

However, while nitrate can often move untransformed through groundwater, the possibility of reactions such as denitrification occuring in the hyporheic zone (the sediments located at the interface between aquifers and streams) prior to discharge into the stream cannot be neglected. The hyporheic zone is widely acknowledged to attenuate nutrients, including nitrate (Bus *et al*, 2009). This is true not only as groundwater passes through the hyporheic zone to discharge to the stream, but also as surface water passes in and out of the hyporheic zone as it flows downstream after having reached the stream. As a result, hyporheic sediments can remove nutrients and thereby ameliorate the downstream impacts of nitrogen loads to stream systems.

Nitrate removal is produced by the biological process of denitrification, which converts nitrate to molecular nitrogen (N_2). Denitrification occurs in environments with little or no oxygen but containing biodegradable organic carbon (Vaccari et al, 2005). Sediments often satisfy this condition as they accumulate organic matter from sedimentation from the water column. The organic matter then decays, rapidly depleting available oxygen. If groundwater containing nitrate percolates up through the sediment from below, then some of that nitrate may then be used to further oxidize the organic matter, and the nitrate is converted to nitrogen. The degree of attenuation is affected by the residence time (determined by permeability and the thickness of the sediment) and the low oxygen concentration (Findlay, 1995). High order streams (those farther from the source) are more likely to have such sediments, although those conditions may occur upstream as well.

In fact, while it is common to observe high levels of nitrate in groundwater associated with agricultural land uses, it is much less common to see the same signature of high nitrate concentrations in the low-flow (baseflow) of streams that drain agricultural lands. As an example from New Jersey, the Raritan River Basin Nutrient TMDL Study (TRC Omni, 2005) measured nitrate in baseflow at many locations unaffected by point sources. Baseflow concentrations of nitrate vary geographically within a fairly narrow range, but show no correlation with land use. It is possible that more data would have yielded some correlation with land use, but the signature is small compared to geographic differences or non-existent. For instance, nitrate concentrations in the baseflow of two of the most agricultural watersheds in the State (Neshanic River and Holland Brook) exhibit baseflow nitrate concentrations of 0.6 and 0.9 mg/l, respectively. Generally, average baseflow nitrate concentrations in the Raritan River basin range from about 0.6-2.2 mg/l, with most locations averaging between 0.7-1.5 mg/l. On the other hand, some types of streams may have little denitrification and have water quality closely coupled to the groundwater quality. For example, it is very possible that hyporheic zones in southern New Jersey may be less important in terms of nutrient attenuation. One reason is that the sediments are more permeable, resulting in a lower residence time within the hyporheic zone. Similarly, small streams through fractured bedrock areas with little sediment may receive groundwater with little chemical change.

2B. What does the literature suggest is an appropriate nitrate standard to protect aquatic ecosystems.

> **Finding:** It would be difficult to try to define a groundwater nitrate concentration that would be protective of surface water ecology.

Basis: It would be difficult to try to define a groundwater nitrate concentration that would be protective of surface water ecology. One reason is that, for the reasons stated in Question 2A, it is not appropriate to assume how much nitrate in groundwater would end up affecting nitrate in streams. In addition, even it an assumption could be made regarding how much groundwater nitrate ends up in the stream, appropriate end points for nitrate in streams from an aquatic ecosystem perspective have not been developed adequately. If the end point of interest is estuarine eutrophication, then the protective value in groundwater would likely be fairly high (not very stringent). The reason is that nitrate from groundwater enters a stream and flows to an estuary before it can stimulate excessive productivity. During that transport, it may be subject to significant loss due to denitrification in the hyporheic zone and uptake by plants and algae in the stream.

Finally, the major contributors of nitrate to surface waters are typically: 1) stormwater runoff, 2) sewage treatment plants, and 3) agricultural use of fertilizer. While the contribution from septic systems would generally be small compared to these three main sources, septic systems may be important contributors in some regions of the state. For example, Wieben and Baker (2009) estimate that 22% of the nitrogen load to Barnegat Bay is from direct groundwater discharge, and 66% from surface water. Since some of the surface water load may originate from septic systems, these may be a significant source in this case. However, the relative impacts from septic systems are influenced by the environment in ways not fully understood at this time. At this time, the Committee would not suggest trying to establish a groundwater nitrate concentration that would be protective of surface water ecology.

The committee expressed some uncertainty about the meaning of the question. Is it intended for the committee to evaluate what an appropriate concentration of nitrate should be in surface water to protect the ecology of the stream? If so, there is a need to evaluate the literature further, before this question could be answered. The Pinelands Commission studies would be helpful in evaluating this issue in that special region of the state.

2C. Does this vary spatially or by receptor?

> **Finding:** Yes, aquatic and marine environments vary significantly in their sensitivity to nitrogen.

The most sensitive receptors for excess nitrate are likely to be estuaries and low nutrient coastal plain streams. Given the nature of estuaries, a load-based regulatory approach (TMDL-type approach) would make the most sense. Such an approach would furthermore be based on total nitrogen, not nitrate alone. At this time, it would not be productive to try to define a groundwater nitrate concentration that would be protective of surface water ecology. See Question 2B above.

Question 3

Background: Land-use decisions are, in some cases, implemented on a lot-specific basis. There may be significant lot-to-lot variation in soil properties, recharge rates and nitrate loading that may create considerable near-source variation in groundwater nitrate values. However, the nitrate dilution models are appropriate at a regional scale.

What are the appropriate scales for applying the results of the nitrate dilution model?

3A. Near field – discharge from septic system to nearby well:

Finding: The dilution model discussed is not appropriate at this scale.

Basis: For the purposes of this report, the near field is defined as the region between an individual septic system and the closest well. This is the smallest spatial scale considered by the committee. There may be preferential pathways through the subsurface that deliver septic design to the well at concentrations much greater than predicted by the model. The model, which assumes uniform dilution by infiltrating precipitation, does not resolve these processes that can concentrate and dilute nitrate as it moves from a septic system to the well.

3B. Medium field – discharge from septic system to groundwater:

Finding: The medium field is appropriate for the dilution model discussed in this report.

Basis: For the purposes of this report we define the medium field as the pathway between a defined number of septic systems and nearby streams through groundwater pathways. Of the scales considered by this committee, the medium field is most appropriate for the dilution model discussed in this report. In the medium field the nitrate is transported in the ground water from the vicinity of the septic system to nearby streams. Nitrate is often considered approximately conservative in these groundwater systems and a steady-state dilution model is tenable when applied at a medium scale to predict the cumulative effects of multiple, individual septic systems on the average concentration of groundwater recharge in the area.

3C. Far field – discharge from septic system to the bay or ocean:

Finding: The Nitrate Dilution Model is not appropriate for predicting impacts at this scale.

Basis: For the purposes of this report we define the far field as the entire pathway from general septic system distribution inshore to the coastal ocean within 100 miles of the coast. This field includes all processes that occur in the groundwater, surface water, estuaries and coastal ocean along that entire pathway. At this scale, the model described in this report is not appropriate. Most septic discharges will "daylight" into surface water far upstream of the ocean. Once the nitrate enters the surface water it will be subject to numerous transformative processes before it reaches the estuaries and eventually the coastal ocean. To model the far field, input from all scales discussed must be parameterized and used as input into downstream models. This dilution model would have to serve as either input into or a component of a larger scale ecosystem model that linked watershed processes to the marine environment by providing estimates of nitrate in groundwater sources that feed the local streams and rivers that eventually make it out to the ocean. A larger scale ecosystem model could then use this input in the modeled processes that transform the nitrate source along the pathway to the coastal ocean.

Question 4

Background: The nitrate coming from one or more ISSDSs can have impacts at three different spatial scales, in groundwater, in nearby streams that the groundwater discharges to, and in distant bays that the streams discharge to.

4. Is it appropriate to use the nitrate dilution model to predict the impact of nitrate coming from one or more ISSDSs at receptors all three of the spatial scales of concern? Is the current model adequate to be protective at all three scales? If not, at which scale is it most appropriate for and what are the preferred models to predict impacts at the other scales?

> **Response:** The SAB merged this question with question 3 in the response to that question above.

Question 5

Background: The nitrate dilution models as applied do not account for any nitrate applied by any other source than the ISSDSs. They do not account for any previous land use that may have been associated with heavy nitrate loadings and thus impacted regional nitrate loadings to aquatic ecologies.

5. Should the standard take into account prior land use and other nitrate sources?

> **Finding:** Nitrate from prior land use is not likely to persist in the environment and does not need to be considered in estimating the nitrate impacts associated with a proposed new development. Control of other on-going nitrate sources should be done separately from the NDM.

Basis: According to the NJDEP, prior sources such as agricultural fertilizer usage are not considered in computing residential development density because the contamination from such sources is likely not to persist on the time scale of the impact of the development. As was described above under question 2A, nitrate in groundwater is highly mobile and will tend to wash out. Thus the NJDEP approach is justified.

Other on-going sources of nitrate include landscape fertilizer, upgradient sources, and residual organic nitrogen or ammonia. Such sources would be difficult to model, and should be managed by other approaches. For example, landscape fertilizer use was discussed above under question 1B, and it was found that there were too many variables and uncertainties to model. Similarly, sources upgradient from a regulated area should be managed separately. More nitrate could be produced by oxidation of organic nitrogen and ammonia, for example from manure piles left after cessation of agricultural activities. Again, such sources should be managed by other approaches.

Question 6

Background: In areas where human activities have impacted groundwater quality, nitrate may be just one constituent out of many to have elevated levels. But because nitrate is relatively conservative in most New Jersey groundwater, and can be easily measured, it is often used as a surrogate for the net impact of development (NJDEP, 2007).

6. Please comment on if it is appropriate to use elevated nitrate concentrations as a surrogate for other excessive anthropogenic impacts on water quality and the ecosystem.

> **Finding:** The Nitrate Dilution Model has potential for assessing impacts from pollutants that pass unmediated to the groundwater. But this represents only the model for dilution and does not necessarily represent the overall impact of land use or potential nonhuman toxicity.

Basis: It was noted that a purpose of a septic system is the oxidation of ammonia to nitrite and then to nitrate. Thus, the presence of nitrate at the end of the septic field indicates that the septic system is working correctly. Nitrate is a conservative parameter in groundwater, and monitoring for nitrate is inexpensive. Furthermore, the concentration of other contaminants in the septic systems should be much lower than the concentration of nitrate. If however the conversion of ammonia to nitrate is not complete then there are implications for aquatic toxicity and the dilution prediction from the model becomes compromised.

Influence of Ammonia to Nitrate conversion:
The nitrogen cycle is carried out by bacteria that convert ammonia to nitrite and ultimately to nitrate. Both steps require oxygen and are carried out by relatively specialized bacteria. The conversion of nitrite to nitrate is a faster reaction than the conversion of ammonia to nitrite. As a result, nitrite usually does not accumulate in the environment. Nitrate is the end product when the system is functioning optimally and can serve as an indicator for breakdown of ammonia. In colder months the rate of conversion could be reduced due to decreased bacterial activity resulting in a build up of ammonia or nitrite. Depending on the proximity of the septic field to surface water and or groundwater seeps, ammonia and or its metabolites could enter into surface waters when the systems are not optimally functioning.

In water ammonia exists in the ionized form ammonium (NH_4^+) and the unionized form ammonia (NH_3). Laboratory analyses typically report total ammonia, which is the sum of the two. Ammonia is much more toxic to aquatic organisms than ammonium. The distribution of the two species depends on the pH. At pH 9.3 half the total ammonia is NH_3. At pH 8.0 it's less than 5% of the total, and at pH 7.0 it's about 0.5%. Thus the sensitivity of aquatic organisms to total ammonia concentration is strongly sensitive to pH. Unionized ammonia concentration below 0.28 mg N/L is generally nontoxic to fish.

Partial oxidation of ammonia can produce nitrite instead of nitrate. Nitrite is highly toxic to fish and invertebrates. Nitrite can bind to hemoglobin and causes "brown blood" disease. Nitrite levels of 0.0 to 0.5 mg/L are generally safe to fish. Levels between 0.6 and 1.0 result in stress, and above 1.1 result in death.

Nitrate is the product of the oxidation of nitrite specialized bacteria. Algae and plants use nitrates for growth, which can contribute to overgrowth in certain water bodies. Canada uses a level of 2.9 mg N/L based on amphibian toxicity.

Thus, each of these compounds (ammonia, nitrite and nitrate) result in toxicity to aquatic species, and would need to be examined individually to determine aquatic toxicity of nitrogen originating in septic systems. This complexity argues against the use of nitrate as an indicator for water quality impact of septic system discharges.

Nitrate as a surrogate for other conservative pollutants:
The use of the Nitrate Dilution Model would be a useful way to assess impacts from pollutants that pass unmediated to the groundwater but this represents only the model for dilution and does not necessarily represent the overall impact of land use or potential nonhuman toxicity. In addition the discussion above on parameters which can effect a complete conversion to nitrate demonstrate that conversion may not always be complete. In instances where the nitrate concentration does not track well with other human land use markers the incomplete conversion may be one explanation.

If one wishes to specifically evaluate the impact of human waste on groundwater, other parameters would be better surrogates. Without a specific human environmental marker coupled to the nitrate concentration, source apportionment becomes much more difficult. There are many potential non-human sources of nitrates only some of which are related to human populations. A human biomarker of diet/activity such as caffeine would be voided in the same fashion as the nitrates, but would be more indicative of human presence and activity. This is true because there are non human sources of nitrate and the only source of caffeine should be human waste. For example studies have shown that while the nitrate is measurable in ground water sources impacted by human septic systems the caffeine often could not be measured. When it was measured it did not correlate well either because of a different sequestering mechanism of the caffeine or the nitrogen values were not predictive of land usage. There is also the probability that the caffeine will undergo different models of biodegradation.

The model of overall impact has to account for many operating parameters that are beyond the scope of this discussion. The question of nitrate as a predictor of other *excessive anthropogenic compounds* requires a more detailed examination than can be covered by the SAB. While some of the limitations are discussed above, many metrics for human septic impact on groundwater sources should also be considered such as coliform, pH, metal contamination and conductivity. There have not been a significant number of studies designed to look at the links between nitrates and other markers of human land use. A relatively new factor includes the impact of other pharmaceuticals and their metabolites. Like caffeine these compounds will undergo different degradation and sequestration mechanisms. Their impact is only beginning to be studied as their discovery as a fundamental indicator of human land usage has only recently been considered.

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