December 23, 2016

Mr. Jeffrey Brem
Lifetime Green Homes
100 Long Ridge Road
Carlisle, MA 01741

Re: Response to Nobis Engineering, Inc.
Phase 4 Report and Technical Memo (12/08/16)
Independent Hydrogeologic Study
100 Long Ridge Road
Carlisle, Massachusetts

Dear Mr. Brem:

Northeast Geoscience, Inc (NGI) has developed the following response to the Nobis Engineering, Inc. report and the subsequent Technical Memo, referenced above.

1.0 PUBLIC WATER SUPPLY

1.1 Maximum Day Demand

A question was raised by Nobis regarding the method used to determine the Maximum Day Demand for a public water supply. As noted in the MassDEP Guidelines and Policies for Public Water Systems (Section 4.3.1.3 1. c.) "For sources seeking approval for less than 100,000 gallons/day, MassDEP shall use Title 5 design flow criteria in assessing minimum pumping test source approval rates, absent other appropriate design flow criteria, such as the limit imposed by the size of the Zone I." Based on the above requirement, NGI has determined that the Maximum Day Demand for the proposed development is the Title 5 flow rate of 6,380 gallons/day or 4.43 gallons/minute over a 24-hour period. In addition, the Zone I and Interim Wellhead Protection Areas (IWPA's) proposed for the site are estimates. Actual wellhead protection areas will be based on approved pumping rates and/or site design requirements.

1.2 Other Public Water Supply Issues

The proposed Public Water Supply wells will be permitted and regulated through the MassDEP. Issued raised by Nobis concerning the proximity of the proposed water supply wells to wetlands, Surface Water Treatment Rule exemptions, potential flow reductions in the intermittent stream due to pumping, potential impacts on nearby private wells and interference between public water supply wells, among others, will be addressed as part of the New Source Approval Process and are outside the authority of local planning. While not required, as a courtesy, the applicant has stated a willingness to copy the Board of Health on the public water supply permitting related correspondence.

2.0 REMAINING ISSUES TO BE RESOLVED

Based on our assessment of the hydrogeologic analyses conducted to date, the items to be resolved include: 1) calculated groundwater mounding at the property line; 2) the use of 110 gallons/day/bedroom (Title 5) versus the Town's 165 gallons/day/bedroom; 3) potential impacts to proposed public water supply wells and existing private wells in the vicinity of the site including well setbacks from the proposed disposal areas; and 4) the modeled limit of 5 mg/l nitrate at the property boundary. These issues are each addressed below.

2.1 Groundwater Mounding at the Property Line

The Town of Carlisle Supplemental Septic System Regulations require that "models shall predict no rise in ground water elevation… at the perimeter boundary". As noted by NGI previously and reiterated by Nobis, the analytical equations used to estimate groundwater mounding cannot produce a mound height of zero feet at any distance. As a result, the ZBA decision noted that, considering the Board of Health's intent to "… limit nitrate impacts of large disposal field discharges across property lines…" the ZBA requested that the Applicant "… limit effluent flows across property lines to no more than 2% of the design wastewater flow entering the disposal field." This requirement is not possible to meet given the nature of groundwater flow.

A conceptual hydrologic model for the site can be stated as:

$$Input - Output = \pm \Delta\ Storage$$

This equation describes how the water table elevation at the site changes based on changes in storage. If inputs (precipitation, groundwater flow to the site, septic system discharge, run-on from adjacent properties, etc.) exceed outputs (evapotranspiration, groundwater flow from the site, run-off to adjacent properties, etc.) the water table will rise as water storage increases by filling the unsaturated pore spaces in the unsaturated zone above the water table. Conversely, if outputs exceed inputs the water table will fall as water is taken from storage by draining a portion of the aquifer beneath the water table. The equation also describes the dynamic nature of the hydrologic cycle since, as a consequence of this equation, all the water that enters the site eventually leaves the site. Therefore, it is not possible to limit the effluent flows across property lines to 2% or any percentage of the "…design wastewater flows entering the disposal field…" since all the water entering the site leaves the site by some means.

In addition, considering the property line setback of 10 feet for a typical septic system, it would appear that septic system approvals in Carlisle routinely allow for some degree of groundwater mounding at property lines. Finally, the groundwater mounds calculated (by Nobis) for the proposed disposal areas under Title 5 flows rates (<2 feet), are within the design criteria to achieve adequate vertical separation from the water table and as stated by Nobis "…probably do not significantly alter the groundwater flow directions at the site…". In addition, the recent Geoprobe testing completed at disposal area two and disposal area three showed bedrock depth and saturated thickness to be significantly greater than previously estimated. The increase in saturated thickness (i.e. increased Transmissivity) will result in a reduced groundwater mounding potential from that previously calculated. Therefore, granting a waiver for provision of the by-law is necessary and reasonable.

2.2 The Use of Title 5 Flow Rates vs Carlisle Flow Rates

The Title 5 flow rate of 110 gallons/day/bedroom is typically used to estimate nitrogen loading rates and groundwater mounding from proposed residential septic systems, and these values were used in our analysis for the proposed development. This per bedroom flow rate is based on a per capita use of 55 gallons/day/person and occupancy of two people per bedroom. The Title 5 occupancy and per capita water use have been shown to be over estimates. According to Cape Cod Commission Technical Bulletin 91-001 (Eichner and Cambareri, 1992) Title 5 design flows "…. are purposely inflated to ensure that the systems avoid hydraulic failure and "assimilate maximum daily flows"…". For comparison with the 55 gallons/day/person wastewater flow used in Title 5, the authors noted "…average residential wastewater flows found in a number of studies averaged approximately 44 gpcd (gallons per capita/day) and occupancy levels found in a number of Cape Cod towns do not approach the two people per bedroom level." According to Costa, et al (1999), beginning in the 1980's the Cape Cod Commission required the use of "… system flows of 212 [liters per capita/day][*46.6 gallons/day/person*] in its assessments to protect drinking water supplies…" and further noted that the "…discharge rates are theoretical maximum system design flows, which are about 25% higher than the typical 167 [liters per capita/day][*36.7 gallons/day/person*] system discharge reported by EPA." Finally, in their Technical Evaluation of Title 5 (commissioned by MassDEP) DeFeo, Wait and Associates (1991) noted that the Title 5 table of minimum sewage flows "… take into account the average daily flow with the appropriate margin of safety…" and stress that care must be taken when estimating wastewater flows "…not to accumulate multiple factors of safety which would yield extremely conservative estimates…" since biomat formation and treatment efficiency can be reduced with an oversized soil absorption area (DeFeo, Wait and Associates, 1991).

The Town of Carlisle septic system flow rate of 165 gallons/day/bedroom appears to have been derived from the garbage grinder requirement in 310 CMR 15.240 (4) which requires a 50% increase in the disposal area. A 50% increase in the 110 gallons/day/bedroom flow rate in Title 5 yields 165 gallons/day/bedroom. While Title 5 requires a 50% increase in the disposal area for garbage grinders, the flow rates are still assumed to be 110 gallons/day/bedroom in term of sizing the septic tank, groundwater mounding, and nitrogen loading calculations. Therefore the use of the Title 5 flow rate of 110 gallons/day/bedroom at 19 mg/l for the nitrogen loading analysis is adequate and preferable, and granting a relief from this requirement is reasonable.

2.3 Potential Impacts to Private and Public Water Supply Wells

Potential impacts to proposed public water supply wells at the site and to existing private wells in the vicinity of the site include water quantity and water quality impacts. Since water quantity impacts on nearby private wells from pumping the proposed public water supply wells is dealt with in the MassDEP permitting process, our discussion here is limited to water quality impacts from proposed wastewater disposal areas at the site.

2.3.1 Nitrogen Loading

The Nobis reports make use of the mass-balance approach for nitrogen loading calculations as described in the MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading. However, according to Ms. Claire Golden of the MassDEP Northeast Regional Office, this nitrogen loading approach is only applicable to sites utilizing credit land. Since no credit land is proposed, this modeling approach is not directly applicable to this project and should not be used. The Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading reference 310 CMR 15.216 as the relevant portion of the regulations and the regulation states:

> *310 CMR 15.216: Aggregate Determinations of Flows and Nitrogen Loadings*
>
> *(1) The 440 gallons per day per acre nitrogen loading limitation imposed by 310 CMR 15.214 may be calculated in the aggregate by using <u>nitrogen credit land</u> in accordance with an approved <u>Facility Aggregation Plan or Community Aggregation Plan</u>* (emphasis added)*. Applicants proposing systems to be located within a community or region covered by a Community Aggregation Plan approved by the Department shall calculate aggregate determinations of flows and nitrogen loadings in accordance with the Plan and the Department's Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading. All other applicants seeking aggregate determination of flows and nitrogen loading shall prepare a Facility Aggregation Plan in accordance with 310 CMR 15.216 and the Department's Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading.*

Also, the Summary Page of the Guidelines specifically state that "Under the provision for Aggregate Determination of Flows and Nitrogen Loadings, 310 CMR 15.216, the nitrogen loading limitation may be calculated in the aggregate through a Community Aggregation Plan, or a site-specific, Facility Aggregation Plan." Since no credit land is proposed here and no Aggregation Plans are proposed, the Guidelines are not applicable to the project. Furthermore, the Introduction section of the Guidelines designates the "… two circumstances in which nitrogen loading may be calculated in the aggregate…" and they are limited to Regional and Facility Aggregation Plans. Finally, Figure 2 of the Guidelines shows a conceptual illustration of the mass-balance method which highlights the point of compliance for the analysis as the down gradient property line of the credit land. As noted above, no credit land is proposed for this project.

Nobis also importantly notes that the nitrate concentration predicted by the mass-balance model "… are not predictive of nitrate concentrations at a given location…" and that the results should be "…interpreted with caution…". In fact the results of the model are not predictive at all. The values obtained by the Title 5 Guidelines mass-balance model allow for a bright-line test for credit land to meet a 440 gallon/day/acre equivalent, and are not intended to be used as a predictive tool. The reasons why the approach should not be considered predictive are inherent in the differences between the nitrate dispersion models presented previously and the mass-balance modeling assumptions. When considering the MassDEP approach in terms of basic hydrogeologic principles, the inherent problems with using this method as a predictive tool are apparent. A detailed analysis of the shortcomings of the MassDEP method as a predictive tool is included in Appendix A and a summary of that analysis is described below.

The MassDEP mass-balance model defines the Area of Impact (AOI) as the area between the upgradient edge of the disposal area downgradient to the point of compliance (such as a property line or drinking water well) and laterally between the groundwater flow divides as determined from a groundwater flow net. All the nitrogen inputs for a year is assumed to mix with the annual groundwater recharge of 18 inches per year. There are significant flaws with this analysis that disqualify its use for estimating nitrogen concentrations on site.

First, the model assumes that all of the nitrogen released stays within the AOI. In fact, due to dispersion, there is a lateral component of solute transport, which increases with increasing distance from the source and results in a nitrate plume wider than the AOI.

Second, groundwater seepage velocity ($V_s=Ki/n_e$) is not considered in the analysis and, in this case, is significant. Based on an estimated average hydraulic conductivity value (K) of ~9 feet/day, an estimated hydraulic gradient (i) of 0.1 and an estimated effective porosity (n_e) of 0.30, a seepage velocity of nearly 1,000 feet/year was calculated for the site. However, the different AOI's estimated for the site are on the order of 300 feet or less. As a result, a significant mass of nitrate would move past the points of compliance on the time scale of the model, significantly reducing the mass of nitrogen in the Area of Influence and, as a result, reducing the projected nitrate concentrations within the AOI.

Third, the AOI depends on the orientation of the disposal area. For all rectangular disposal areas the size of an AOI changes as the system is rotated. While this consequence is not troublesome per se, the fact that the mere orientation of a disposal area could be the deciding factor in the success or failure a mass-balance loading analysis, calls into question the validity of the modeling approach as a predictive tool. For these reasons, the dispersion models presented previously better represent expected solute concentrations at the site, since the dispersion model reflects the solute concentration at specific locations in three-dimensional space over time.

An example of the predicted nitrate Plume vs the AOI for disposal area two is included as Figure 3 - Appendix A to illustrate the dispersion and seepage velocity issues noted above. As can be seen on Figure 3, a significant portion of the projected nitrate plume exists outside of the area of impact for the reasons described above and the model projected nitrate concentrations are significantly lower than the values obtained by the mass-balance model. Figure 4 – Appendix A illustrates item 3 noted above. As can be seen on Figure 4, the AOI for the rectangular system shown, changes by more than 50% when the disposal area is rotated 90 degrees.

Considering the results of the nitrate dispersion models completed to date, with projected nitrogen concentration in the overburden at nearby private wells below the 5 mg/l drinking water action level and well below the 10 mg/l drinking water standard, the nitrogen impact analyses for nearby private wells are satisfactory.

Additionally, the issue of nitrate concentration on this project is primarily due to a waiver request by the applicant from the local Carlisle Board of Health regulation which states for "(s)ystems having a design wastewater flow of 2,000 gallons per day or greater, a hydrogeological evaluation utilizing a three dimensional model such as ModFlow shall be performed by a qualified engineer or geologist, at the expense of the applicant, to be reviewed and approved by the Board of Health prior to the issuance of a DSCP". The requirement is for a three dimensional model. The mass-balance model is not a three dimensional model and it should not be used as method for modeling nitrogen in septic effluent in order to meet the local by-law. By comparison, the dispersion model presented by both Nobis and NGI is a three-dimensional model and represents a conservative approach to estimating solute concentrations from constant sources such as septic systems. In their comparison of a dispersion model (Domenico) with that of ModFlow, Cecan and Schneiker (2008; and personal communications) found that the Domenico based models produced overestimates of downgradient concentrations for conservative solutes in moderately permeable soils.

Nobis does note that the dispersion model and the nitrogen loading model taken together can be used to "…identify areas where impacts to groundwater due to septic discharges are likely to be greater or lesser", yet the analysis and testimony to date appear to favor the results of the mass-balance model over the dispersion model. For the reasons stated above, the mass-balance model is not applicable to this project. If both models are truly "useful when taken together" as stated by Nobis, then they should be used together; the Mass-Balance model as a first approximation to identify areas of concern and, where necessary the use of the dispersion model as a more definitive yet still conservative model, to further refine the analysis.

2.3.2 Hydraulic Connection Between Overburden-Bedrock

A discussion is included in the Nobis report on the potential for groundwater in the overburden to recharge the bedrock aquifer at the site. Field activities including soils borings and water level monitoring were conducted by Nobis in an attempt to address this concern.

2.3.2.1 Basal Till

The Nobis report suggests that the presence of a dense basal till layer at the site would provide indirect evidence of limited groundwater communication between the overburden and the bedrock. To test this hypothesis a soil boring was advanced near each of the proposed disposal areas by Nobis to identify the presence of a basal till layer, and the work was observed by NGI personnel. Dense glacial till deposits were identified at disposal area two and disposal area three, but not at disposal area one (see Nobis Technical Memo for a details discussion of the field work conducted). Nobis suggests that a since no basal till layer was noted during the installation of monitoring wells MW-4 and MW-5 that none exists at these locations and that the basal till noted in the vicinity of disposal areas two and three is discontinuous. It is important to note that no soil samples were collected by NGI during the installation of monitoring wells MW-4 and MW-5 and that soil interpretations were made from the auger cuttings. It is also important to note that auger refusal at disposal area three is proximal to the depth of the top of the basal till layer at that location, suggesting that auger refusal at MW-4 and MW-5 could also be due to the presence of a basal till deposit. Finally, the claim by Nobis that a basal till deposit may not be present at monitoring wells MW-4 and MW-5 was known at the time of the recent drilling operations, yet no attempts was made by Nobis to confirm this through soil borings. This fact calls into question the need for the additional soil borings. Since, according to Nobis, the presence of a basal till at disposal areas two and three does not resolve the potential impacts from discharges at those locations.

The ultimate factor in determining the potential impact to nearby sensitive receptors is the nitrate concentration distribution at the bedrock surface, since flow from the overburden to the bedrock aquifer is the main concern. The depth to bedrock at the site is equal to or greater than approximately 11 feet. Using the dispersion model, we calculated the nitrate concentration versus distance from the disposal area at a depth of 11 feet and the results are shown on Figure A. As can be seen on Figure A the projected nitrate concentration increases to a maximum of approximately 5.0 mg/l at a distance of 80 feet from the source and then decreases. Based on this analysis a bedrock fracture communicating with the overburden aquifer located at a distance of 80 feet from the disposal area could receive approximately 5.0 mg/l of nitrate, or roughly half of the maximum contaminant level for drinking water. This 5.0 mg/l would then need to be transported along a bedrock fracture that contributes water to a nearby private well. Even assuming no dilution during the travel time through the bedrock, it is unlikely that the nitrate concentration would exceed the drinking water threshold, especially given the fact that water level monitoring showed no significant influence on the overburden aquifer due to pumping of bedrock wells (as discussed below).

2.3.2.2 *Water Level Monitoring*

Electronic data logging pressure transducers were installed by Nobis in the overburden wells on site to monitor water table changes, in an attempt to identify of a hydraulic connection between bedrock groundwater and overburden groundwater. The goal of the water level monitoring was to identify periodic water level changes in the overburden due to pumping of the bedrock wells in the area. A detailed discussion of the data loggers installation is included in the Nobis Technical Memo. As noted by Nobis, "…Water levels in MW-1, MW-2, MW-3, and MW-4 show net increases of less than one foot during the monitoring period. MW-5 declined more than two feet during the monitoring period…" and "…No fluctuations that might be due to pumping of nearby wells are evident in MW-2, MW-3, or MW-4…". While very small periodic changes can be seen on the graphs for MW-1 and MW-5, on the order of a few hundredths of a foot, the data "cannot be conclusively proven to reflect pumping in neighboring wells." Water level monitoring within the overburden did not identify a hydraulic connection between the overburden and the bedrock aquifers at the site.

2.3.2.3 Water Quality Data

To further support the interpretation of limited bedrock-overburden communication at the site, we offer water quality data obtained from the private wells serving 100 Long Ridge Road and 90 Long Ridge Road, previously presented by NGI, as strong and direct evidence for limited overburden-bedrock communication.

The well serving 100 Long Ridge Road is located adjacent to and immediately downgradient of the horse paddocks at the site. Horses boarded at the site have been a continuous and significant source of nitrate since approximately 2005. However, no nitrate was detected in the water sample collected from the well serving 100 Long Ridge Road.

In addition, the well serving 90 Long Ridge Road is located hydraulically downgradient of the manure pile at 100 Long Ridge Road. The well was installed around April 2015. A manure pile has been present at the site, continuously at the site since around 2005. Water quality data obtained from the Carlisle Board of Health showed the sample collected from the well at the end of the pumping test contained 0.05 mg/l of nitrate, which may be considered background concentrations. In addition, at the time the field work was conducted for our original hydrogeologic investigation, this well was observed to be flowing, indicating artesian conditions within the bedrock. The favorable water quality results and the artesian conditions observed at the well site offer direct evidence of limited overburden-bedrock communication.

The Nobis Technical Memo questions the validity of using the existing manure pile to draw conclusions about nitrate loading at the site. However, livestock is included as an input parameter for the MassDEP's Nitrogen Loading Computer Model used for Zone II Wellhead Protection Area analysis and the nitrogen input values for horses (as noted in our original evaluation) are not insignificant. In fact, the overall nitrogen inputs to the site are expected to decrease as a result removing the horses from the property, even with the proposed wastewater increases.

The Nobis Technical Memo also refers to water quality data obtained from the Carlisle Board of Health records for other private water supply wells in the area and notes that the results "…are encouraging and may suggest that the soils and groundwater in the Long Ridge Road area may be capable of accepting nitrates discharging to overburden groundwater without impacting active bedrock wells…".

2.4 Well Setbacks from Proposed Disposal Areas

The Water Quality and Water Quantity Conditions established in the ZBA Decision call for compliance with the 150 foot setback for private wells from the septic systems. Of the private wells surrounding the site, the well serving #132 Long Ridge Road does not meet this requirement at disposal area three. The disposal area does however meet the MassDEP Title 5 setback of 100 feet from a private well. Interestingly, the septic system setback from a public water supply with a maximum yield of 0.7 gallons/minute or over 1,000 gallons/day is only 100 feet. This is the equivalent design flow of more than two four-bedroom single-family homes. If a public water supply can be located within 100 feet of a septic system, it would seem reasonable in this case that a 100 foot setback would be in adequate to protect public health for one single family home, especially considering the fact that groundwater flow in the area is to the east-northeast, according to Nobis little to no groundwater flow is to the west, and that a dense glacial till is present beneath disposal area three. For these reasons, the reduction of the private well setback from 150 feet to 100 feet is reasonable and complies with the minimum setback for public water supplies from septic systems.

2.5 5 mg/L Limit at the Property Boundary

The ZBA Final Decision denies the Applicants request for a waiver of the Supplemental Septic Regulations constraint that models predict "… no greater than 5 mg/L of total nitrogen at the perimeter boundary." Modeling requirements described under the MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading, while not an applicable model for the reasons described above, are useful for understanding other regulatory goals for nitrate modeling in nitrogen sensitive areas. The Guidelines set a 10 mg/L standard at the downgradient credit land property boundary or nearest sensitive receptor "…to ensure protection of public health and the environment." It is important to note that this standard uses either the down gradient credit land boundary or the nearest sensitive receptor as the point of compliance. Considering the mass-balance model is established for design flows greater than 2,000 gallons/day, it would seem reasonable and fair to apply a similar standard in this case, where design flows are less than 2,000 gallons/day.

3.0 CONCLUSIONS

As a result of the field investigations by NGI and Nobis, nitrogen dispersion modeling, private well water quality data and water level monitoring recorded at the site we come to the following conclusions:

- No direct impacts to private wells from existing land uses (both on and off site) have been shown.
- No water quality impacts to private wells are predicted using solute transport modeling of nitrogen in the overburden aquifer.
- No direct evidence of communication between the overburden and bedrock aquifers has been shown using both water quality and water level data.
- Groundwater mounding estimates have been shown to be within standard septic design parameters.
- The AOI method should not be used a predictive tool for non-credit land projects such as this, and that a three-dimensional model, such as a dispersion model, should be used as required in the by-law.

If you have any questions or require additional information, please do not hesitate to contact me.

Sincerely,
Northeast Geoscience, Inc.

Joel Frisch
Hydrogeologist

4.0 REFERENCES

Cecan, Liliana and Schneiker, Robert A. 2008, "BIOSCREEN, AT123D, And MODFLOW/MT3D, A Comprehensive Review Of Model Results," Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy: Vol. 13, Article 22.

Costa, J.E., B. L. Howes, D. Janik, D. Aubrey, E. Gunn, A. E. Giblin. 1999. Managing anthropogenic nitrogen inputs to coastal embayments: Technical basis of a management strategy adopted for Buzzards Bay. Buzzards Bay Project Technical Report. 62 pages.DeFeo, Wait and Associates (1991)

DeFeo, Wait & Associates, et al. 1991. Technical Evaluation of Title 5 The State Environmental Code 310 CMR 15.00.

Eichner, E.M. and T.C. Cambareri. 1992. Nitrogen Loading, Technical Bulletin 91-001. Cape Cod Commission. Water Resources Office, Barnstable, MA.

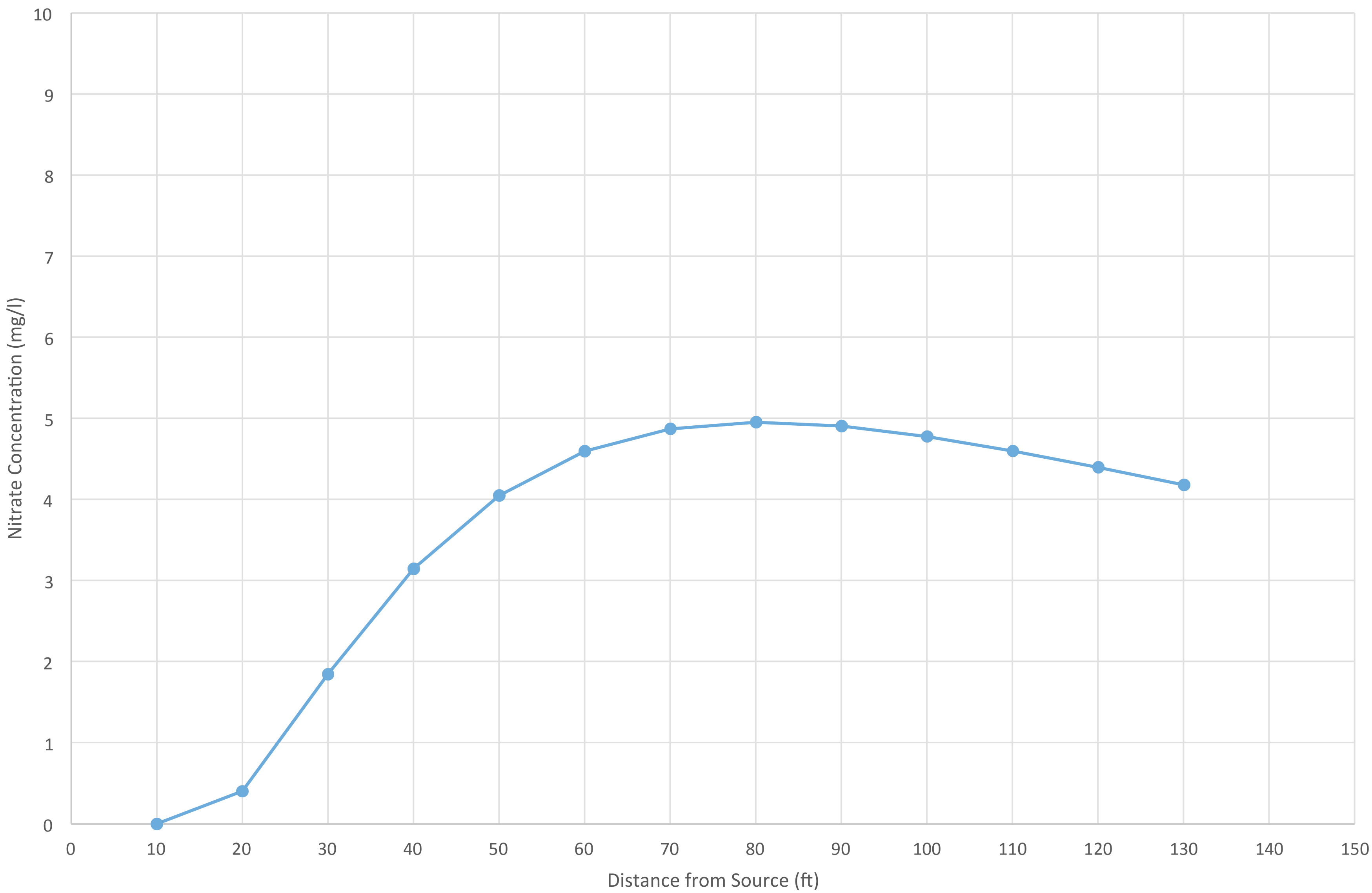
FIGURES

NORTHEAST GEOSCIENCE INC
Water Supply & Environmental Consulting

FIGURE A

Nitrate Dispersion Model

Concentration vs Distance at 11 ft depth or "estimated bedrock surface"



APPENDIX A

NORTHEAST GEOSCIENCE INC
Water Supply & Environmental Consulting

Shortcomings of the Title 5 Aggregation of Flows and Nitrogen Loading Model as a Predictive Tool for Estimating Nitrate Concentrations in Groundwater and Difficulties with Using This Approach as a Planning Tool for Non-Credit Land Projects

Joel Frisch, P.G.
Northeast Geoscience, Inc.
Clinton, Massachusetts

Abstract

Mass-balance loading models are widely used to develop steady-state estimates of conservative solute concentrations such as Nitrate and Sodium in public water supply groundwater recharge areas due to their ease of set-up and use and their flexibility in estimating long-term conditions or to compare relative impacts from proposed land use changes. However, the ease or set-up and flexibility can also result in the misapplication of these models by ignoring the basic model assumptions and how the models relate to physical hydrogeologic processes. One such misapplication of this modeling approach is that defined in the MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading 310 CMR 15.216. This paper applies basic hydrogeologic principles to the mass-balance approach defined in the guidance document and outlines why the model results should be considered a regulatory bright-line test for meeting a regulatory threshold and not a predicted point concentration.

Introduction

The MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading 310 CMR 15.216 apply a Site-Specific Mass-Balance Analysis for discharges of greater than 2,000 gpd but less than 10,000 gpd that propose to meet the 440 gpd per acre equivalency standard by establishing nitrogen credit on non-facility land as a means to demonstrate that the groundwater quality standard (10 mg/l nitrate-nitrogen and 10 mg/l total nitrogen) at the credit land property boundary or nearest sensitive receptor will be met. This approach provides a bright-line test for proposed developments that do not meet the 440 gpd/acre standard by requiring a set-aside of development-restricted land. The goal of this paper is to show the shortcomings of this approach as a predictive tool for nitrate concentration in groundwater and the problems with using this approach as a planning tool for non-credit land projects.

The Mass-Balance Method

The general mass-balance modeling method estimates future Nitrate concentrations in groundwater by applying literature or regulatory estimates for a variety of land uses and on-site activities as a means to calculate the total annual mass of nitrogen input to the model area. The method also applies estimates of annual groundwater recharge to the model area based on precipitation, wastewater flows, stormwater flows, irrigation etc. The ratio of the total mass of Nitrate per total groundwater recharge volume provides an estimate of steady-state nitrate concentration in groundwater. This approach, as described by Frimpter (et al, 1988) was originally applied to the delineated zones of contribution to high-yield groundwater sources, since *"… all ground water flows toward and converges at the well. This results in a complete mixing effect of the water (and associated contaminants) at the well as it is withdrawn from the aquifer."* Therefore, the distribution of the individual nitrate loads throughout the recharge area and the various flow paths and time of travel are irrelevant since complete mixing and dilution are assumed at the well and equilibrium is assumed to be achieved only after several years or decades. The authors note "*The nitrate concentrations calculated by this approach are intended to be a guide for broad decisions on limiting land uses that increase concentrations in water-supply wells.*" And that the "… *calculations also can be used to assess the relative effects of various specific land uses or levels of development*…". They also noted that the method "…*is not appropriate for determining contaminant concentration at other points within the aquifer, or determining the concentration in any smaller (private domestic supply) wells within the zone of contribution*" since mixing is incomplete.

Aggregation of Flows and Nitrogen Loading Approach

The mass-balance method used for Title 5 Aggregation of Flows uses an approach similar to the Frimpter Method for estimating Nitrate loads and groundwater recharge volumes. But rather than using the delineated zone of contribution for a high-yield groundwater source, the approach involves the delineation of an Area Of Impact (AOI) from a wastewater discharge. The AOI is delineated using flownet analysis and is defined as the area extending from the upgradient edge of the discharge area to the downgradient credit land boundary, with the lateral extent delineated from the groundwater divides developed at the groundwater discharge area for design flows and considering the effects of groundwater mounding (if significant). Within the AOI the impacts of Nitrate inputs from wastewater discharges and fertilizer only are estimated along with recharge from precipitation to calculate nitrate concentrations by dilution (see Figure 1). At first glance this approach would appears to be a reasonable adaptation of the Frimpter method. But further analysis when considering groundwater seepage and solute transport mechanisms reveals the methods shortcomings.

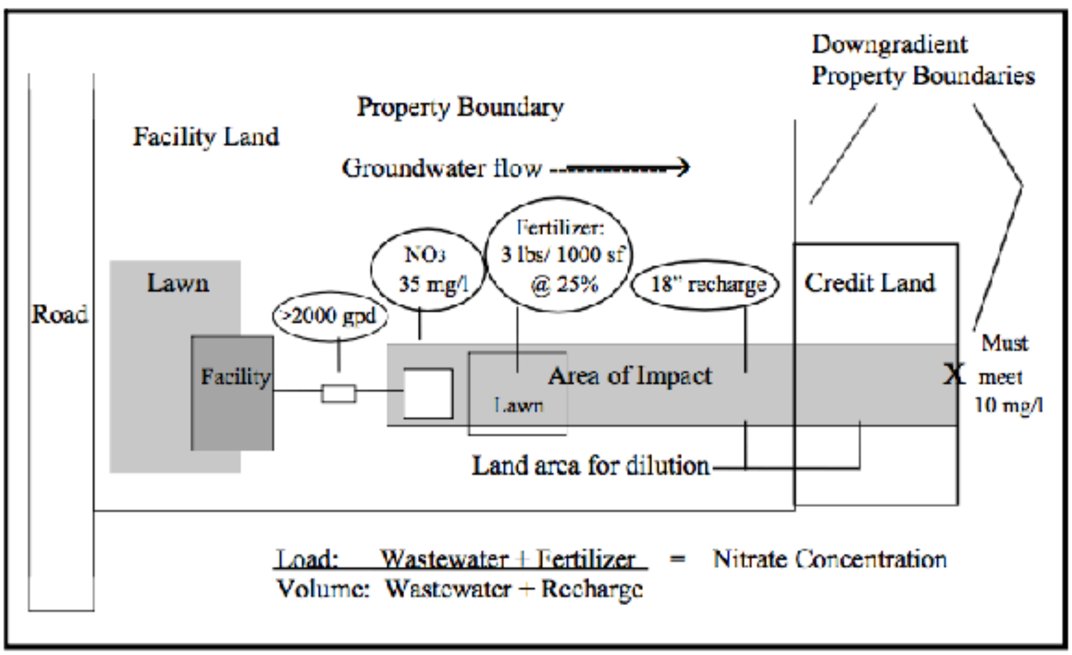


FIGURE 1. MASS-BALANCE MODEL AS DEFINED BY MassDEP GUIDELINES FOR TITLE 5 AGGREGATION OF FLOWS AND NITROGEN LOADING.

The assumptions implicit in the modified mass-balance approach assume solute movement is limited to transport along groundwater flow paths from groundwater discharges, which define the lateral edges of the AOI, and that attenuation is limited to dilution from groundwater recharge. In addition to being a misapplication of the mass-balance technique, based on the assumptions described previously, the method contains at least two major flaws that in many cases significantly overestimate nitrogen concentrations at the downgradient point of compliance.

Groundwater Seepage Velocity

The Title 5 Aggregation of Flows Mass-Balance Model calculates nitrate concentrations based on annual Nitrate inputs and annual recharge to the AOI. However, this approach treats the AOI is as an impermeable box that captures all of the nitrogen and all of the recharge that occurs annually. This approach could be considered a reasonable approximation where the distance traveled by the solute plume emanating from the groundwater discharge is equal to the length of the AOI. However, in cases with a higher seepage velocity where the length of the solute plume after one year of operation exceeds the length of the AOI, the resulting mass-balance Nitrate concentrations in groundwater would be significantly overestimated since a significant percentage of the solute mass would have left the limits of the model (i.e. the AOI).

A proposed groundwater discharge in the Town of Carlisle was used as a case study to illustrate this condition. An on-site wastewater disposal system was designed to accept of 1,980 gpd of partially treated wastewater. The AOI for the proposed discharge was delineated from the upgradient edge of the disposal area to a proposed community public water supply well. The length of the delineated AOI was approximately 300 feet. An average hydraulic conductivity value of 9 feet/day (3,285 ft/yr) was calculated for the site based on a series of rising-head slug tests and low-flow pumping tests. The unconsolidated materials at the site consisted of sandy glacial till deposits ranging in thickness from 10-12 feet. Observed water table depths ranged from 3-6 feet below ground surface, with saturated thickness ranging from 8-10 feet. The average hydraulic gradient measured for the site, based on groundwater contour maps was 0.10 and porosity was estimated at 0.30 with an effective porosity of 0.25. Based on these values a groundwater seepage velocity was estimated as follows:

$$V_s = Ki/n_e = (3{,}285 \text{ feet/year} \times 0.08) / 0.25 = 1{,}051 \text{ feet/year}$$

Where: V_s = *average groundwater seepage velocity (feet/year)*
K = *average hydraulic conductivity (feet/year)*
i = *average hydraulic gradient*
n_e = *effective porosity*

The estimated seepage velocity (>1,000 feet/year) would result in a plume length greater than the length of the AOI for the site (300 feet) by a factor of three. As a result the area of the solute plume would be significantly larger than AOI delineated for the disposal area and the mass of solute remaining in the AOI would be greatly reduced. This analysis clearly shows that the Title 5 Aggregation of Flows Mass-Balance Model would significantly over estimate the Nitrate concentration, since the a large portion of the solute mass would be transported past the downgradient limits of the AOI. By comparison, the method described by Frimpter (et al, 1988) accumulates and mixes the groundwater recharge and the solute inputs from all points within the aquifer contributing to the groundwater source, yielding a reasonable steady-state solute concentration.

Advection-Dispersion

The mechanisms involved with solute transport in a porous medium include advection, molecular diffusion, mechanical dispersion and adsorption (Ogata, 1970). Advection describes mass transport simply due to the bulk flow of water in which the mass is dissolved. Advection is the primary process by which solutes move in groundwater. The direction and rate of solute transport corresponds to that of groundwater. Dispersion refers to the spreading and mixing caused by flow path and velocity differences (mechanical dispersion) and spreading due to concentration gradients (molecular diffusion), collectively known as hydrodynamic dispersion which operates at the pore channel scale. Adsorption refers the interaction of a solute with the porous media, which tends retard the flow of the solute. While an important mechanism for some solutes, such as organic compounds, the role of adsorption is limited with conservative solutes.

In a granular porous medium, different stream lines converge in the narrow necks between particles and diverge in the larger interstices, resulting in an intermingling of streamlines, which causes transverse dispersion or solute transport at right angles to the direction of groundwater flow as shown on Figure 2 (Heath, 1982). Through the mechanism of hydrodynamic dispersion plume width increases downstream of the solute injection, which in this case would result in the transport of a portion of the solute mass outside the flow lines used to define the AOI. By ignoring this process, the nitrate concentrations estimated by the Title 5 Aggregation of Flows Mass-Balance Model at downgradient points of compliance tend to be overestimated. Using the field example cited above we show how ignoring the effects of hydrodynamic dispersion also leads to overestimates of nitrate concentrations using the AOI approach.

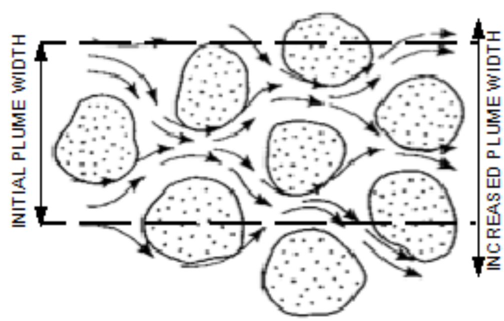
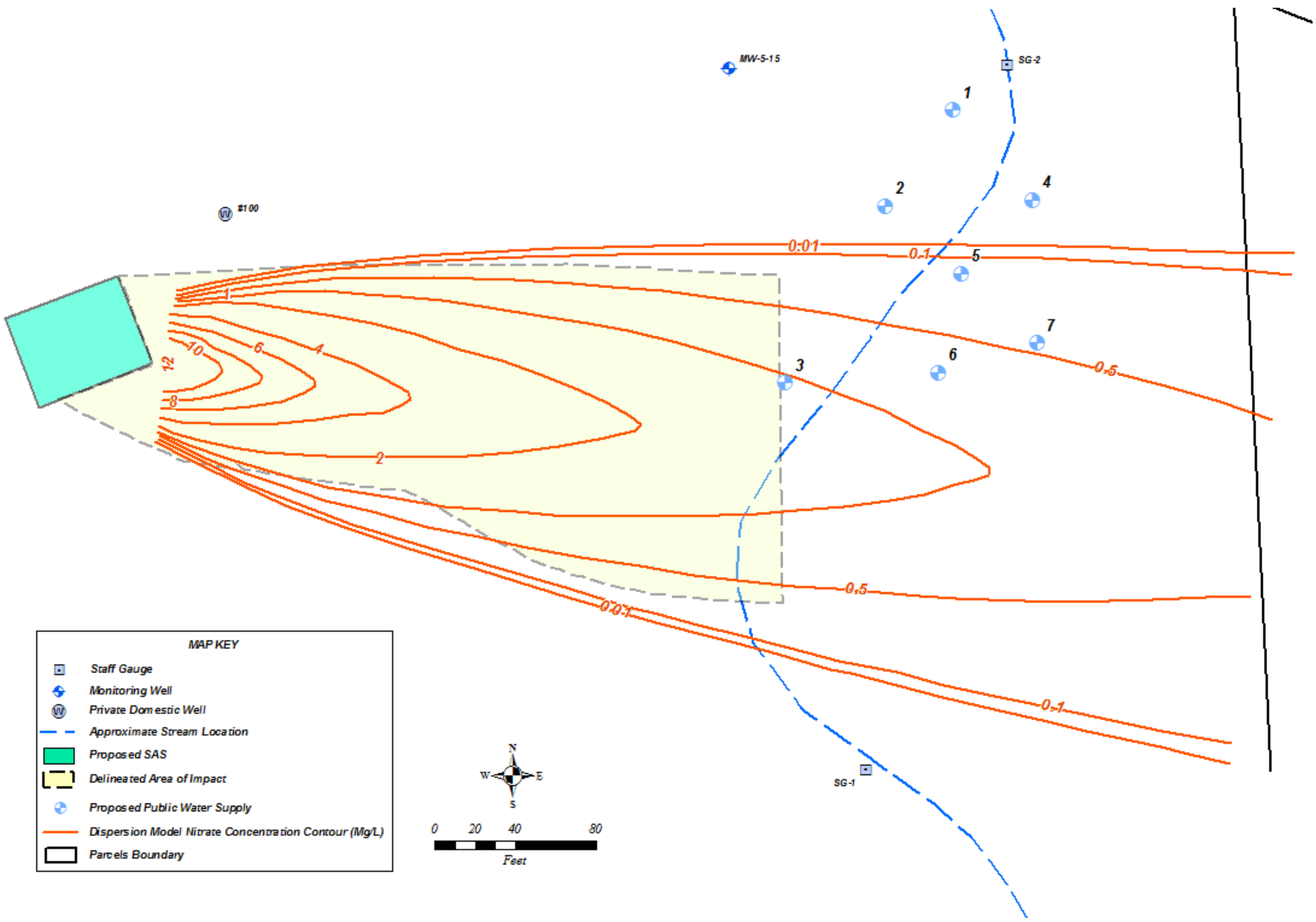


FIGURE 2. THE SPREADING AND MIXING AFFECT OF MECHANICAL DISPERSIONIN A POROUS MEDIA.

A septic system proposed for a residential development in Carlisle, Massachusetts was designed to accept up to 1,980 gpd of partially treated waste water with average nitrate concentrations of 19 mg/l. The proposed septic system and the surrounding site are shown on Figure 2. Based on the procedure described in the Title 5 Aggregation of Flows Mass-Balance Model the AOI was delineated and a nitrate concentration of 15.4 mg/l was calculated based on the procedures defined in the MassDEP Guidelines. In addition, using the analytical solute dispersion equation described by

Domenico (1987) a nitrate plume was calculated for the proposed septic system based field derived parameters and literature estimates and the results are superimposed on the AOI delineated for the site. As can be seen on Figure 2 the calculated nitrate plume for site shows solute mass outside the lateral limits of the AOI and past the downgradient limit of AOI. This figure clearly shows the effects of transverse hydrodynamic dispersion and the solute distribution when the annual groundwater transport distance exceeds the downgradient limits of the AOI. It is important to note that the nitrate concentration estimated by the dispersion model for the same point of compliance is <2 mg/l, significantly lower than the 15.4 mg/l calculated by the Title 5 Aggregation of Flows Mass-Balance Model.



FIGUE 3. ANALYTICAL DISPERSION MODEL CONCENTRATIONS VERSUS LIMITS OF "AREA OF IMPACT"

Disposal Area Orientation

As noted previously, the Area of Impact delineated under the MassDEP Title 5 Aggregation of Flow includes the portion of the site extending from the upgradient edge of the discharge area to the downgradient credit land boundary and laterally to the groundwater divides developed at the groundwater discharge area for design flows and considering the effects of groundwater mounding, if necessary. Based on this approach the orientation of the disposal area determines the size of the Area of Impact. Therefore two disposal areas with the same area and discharge rate (i.e. same groundwater loading rate) will have different Areas of Impact. An example of this is shown on Figure 4.

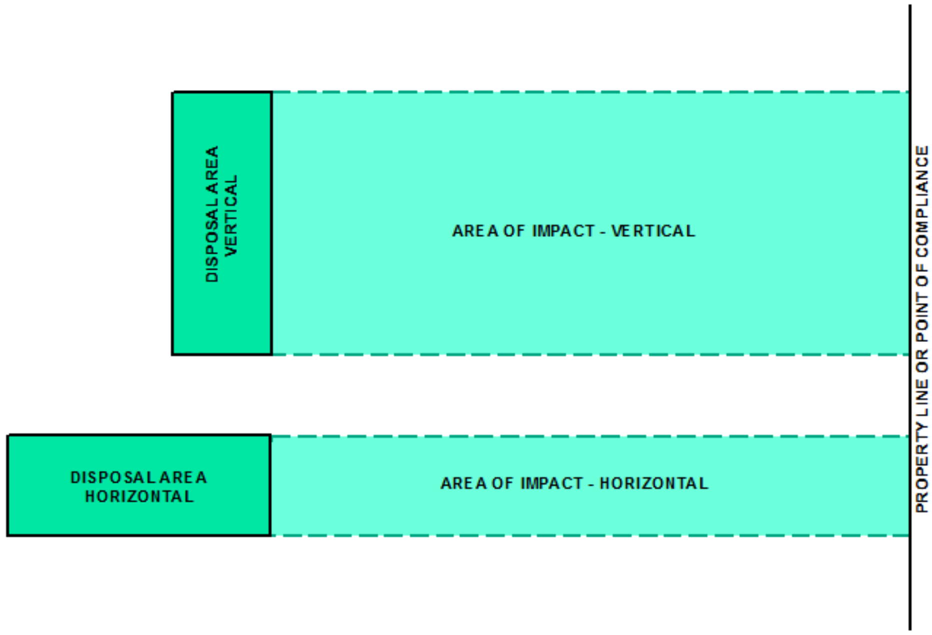


FIGURE 4 - AREA OF IMPACT AS A FUNCTION OF DISPOSAL AREA ORIENTATION

As can be seen on Figure 4, two different Areas of Impact result from a vertical layout versus a horizontal layout for the same disposal area. As a result the two systems, though of the same footprint and loading rate, will yield different nitrogen concentrations using the MassDEP nitrogen loading model, depending on how the disposal areas are oriented.

Conclusions

The mass-balance nitrogen loading approach described in the MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading provides a bright-line test for proposed developments that do not meet the 440 gpd/acre standard, by establishing a threshold for developers to meet for the set-aside of development-restricted land. While this method provides a clear test for meeting the regulatory goal set by MassDEP, the model should not be considered a predictive model for estimating nitrate concentrations. As a predictive tool the MassDEP approach fails to meet the basic assumptions of the method described by Frimpter et al (1988), yields different results depending on the orientation of the disposal area and does not consider basic hydrogeologic principles of groundwater seepage velocity and hydrodynamic dispersion. These shortcomings render the use of the modified-Frimpter approach as a predictive tool, untenable.

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