January 3, 2017
File No. 89220
Via Email and U.S. Mail

Town of Carlisle, Zoning Board of Appeals
ATTN: Steve Hinton
66 Westford Street
Carlisle, MA 01741
shinton@mindspring.com

Re: Response to NGI 12/23/16 Report
Independent Hydrogeologic Study
100 Long Ridge Road, Carlisle, MA

Dear Mr. Hinton:

Nobis Engineering, Inc. (Nobis) is pleased to present this report to the Town of Carlisle Zoning Board of Appeals (Town; ZBA) as part of Phase 4 of an independent hydrogeologic study of potential impacts related to a proposed 40B housing development on the Brem property at 100 Long Ridge Road in Carlisle, Massachusetts ("Site"). The Site is Carlisle tax lot 1-72-33K, with the subtraction of a lot for a new home at 90 Long Ridge Road. This report is an additional deliverable item for Phase 4 of the project under Nobis' contract with the Town, dated January 2015 (Town of Carlisle document # Brem 151 01-14-2015), with Amendment 5, dated August 8, 2016 to the existing contract and additional work added via Amendment 6, dated October 24, 2016, and informally, by email on December 27, 2016. (Phase 2 included additional hydrogeologic work conducted by Nobis in 2015, and Phase 3 included Nobis support at the Housing Appeals Committee (HAC) mediation in 2016; these were covered by previous amendments.)

A letter report dated September 30, 2016 (Brem 310 – 314 09-30-16) was the primary deliverable product under Amendment 5, and Technical Memoranda dated October 25, 2016 (Brem 322 10-25-2016) and December 8, 2016 (Brem 330 12-08-2016) were submitted to the Town under Amendment 6. The current letter report is authorized and requested by the informal email amendment dated December 27, 2016.

1.0 INTRODUCTION

Nobis understands that the 9.84-acre Site is proposed for development by a private owner and that the Town's concerns include potential impacts of proposed, on-Site, wastewater disposal systems on proposed on-Site and existing off-Site drinking water wells, and potential yield and water level effects between the proposed new wells and the existing off-Site wells. Also, potential interference effects between the proposed new wells are a concern.

The Town granted conditional approval for the proposed 40B housing development in 2015. However, the developer, Lifetime Green Homes (Applicant), appealed the Town's decision to the HAC, seeking relief from the conditions. The Town and the Applicant met with a mediator assigned by the HAC in March 2016. In April 2016, the Applicant submitted a modified proposal

Nobis Engineering, Inc.
18 Chenell Drive
Concord, NH 03301
T (603) 224-4182

whose significant differences from the original proposal were summarized in Nobis' September 30, 2016 report (Brem 310 – 314 09-30-2016).

The proposed new wells and new SDAs are shown on a map entitled "Plan P – Public Water Supply, The Birches", dated February 2, 2016 (Brem 300 08-22-2016, included as Attachment A in Nobis' September 30, 2016 report).

Phase 4 included Tasks intended to address the following objectives:

- Assess the potential impacts of the re-configured septic systems on existing neighbors' wells;
- Assess the potential impacts of the re-configured septic systems on proposed new wells for the Birches PWS; and
- Assess the potential impacts of pumping the proposed new PWS wells on existing neighbors' wells and on each other.

The objective of this letter report is to comment on selected aspects of the NGI report dated December 23, 2016, "Response to Nobis Engineering, Inc., Phase 4 Report and Technical Memo (12/08/16)" (Brem 334 12-24-16).

2.0 BACKGROUND

See Nobis' September 30, 2016 report for project background and a summary of previous investigations.

3.0 DISCUSSION OF NGI REPORT DATED DECEMBER 23, 2016

The following discussion is arranged by topic, in the approximate order that these topics were discussed in the NGI report.

3.1 Groundwater Mounding at the Property Line

The NGI Report, Section 2.1, 1st paragraph states that the Carlisle ZBA's 2015 decision "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 …." Nobis agrees that the requirement is not possible to meet and that the amount of effluent flow crossing the property line would be difficult to quantify. To achieve the ZBA's goal of limiting nitrate impacts across a property line, the ZBA could consider modifying the requirement to stipulate that mounding would not be expected to increase the saturated thickness of the overburden at the property line by more than 2%. This is a more theoretically reasonable requirement, but the mound height analyses performed by Nobis in 2015 and 2016 (September 30, 2016 Nobis report) are not sufficient to make this determination, as Nobis' model only predicts maximum mound height and not the mound height at any specific down-gradient location.

The NGI Report, Section 2.1, 3rd paragraph states that "the groundwater mounds calculated (by Nobis) for the proposed disposal areas under Title 5 flow rates" will "achieve adequate vertical

separation from the water table ….". However, our results (Nobis September 30, 2016 report, Table 2) show predicted separation of less than 5 feet beneath SDA2 and less than 4 feet beneath SDA3. Nobis did not emphasize this point in our report, because recommending that a permit be granted (or not) under Title 5 or local regulations was not one of Nobis' objectives. However, Title 5 requires the separation between the top of the groundwater mound and the "bottom of the stone underlying the soil absorption system" to be either 4 or 5 feet, depending on the percolation rate (310 CMR 15.212). Note further that the estimated mound height must be included in a Title 5 submittal because the proposed flow is greater than 2,000 gallons per day (gpd). Past correspondence with MassDEP (Brem 309) indicates that MassDEP will consider the SDAs for this project as a single septic system.

The NGI Report, Section 2.1, 3rd paragraph also quotes from Nobis' conclusion in our September 30, 2016 report, that "the groundwater mounds … 'do not significantly alter the groundwater flow directions at the site'". NGI omitted key portions of the sentence in Nobis' conclusion that change the meaning; our sentence reads "These groundwater mounds can be expected to increase groundwater gradients and flow velocities and <u>may create radial flow in the immediate vicinities of the proposed SDAs</u>, but do not significantly alter the groundwater flow directions at the <u>Site scale</u>."

The NGI Report, Section 2.1, 3rd paragraph also states that the increase in saturated thickness indicated by the 2016 borings "will result in a reduced groundwater mounding potential from that previously calculated". Nobis agrees for SDA3, but the amount of the mound height decrease depends on whether the clay layer at 17 feet below ground surface (ft bgs) is considered the bottom of the saturated zone to be modelled or whether the effective bottom of the saturated zone is 30 ft bgs or deeper (see boring logs in Nobis September 30, 2016 report). Nobis disagrees with the NGI conclusion for SDA1; boring results do not indicate a significantly greater saturated thickness than that used in previous calculations, so the mound height would probably not be significantly different from the height previously calculated. For SDA2, there is still no location-specific information on hydraulic conductivity or depth to water, so mound height estimates in this area cannot be confidently refined.

3.2 Potential Impacts to Private and Public Water Supply Wells

The NGI Report, Section 2.3, 1st paragraph indicates that NGI is not discussing potential water quantity effects because these will be "dealt with in the MassDEP permitting process". However, assessing these impacts was one of Nobis' objectives. We stand by our conclusion (Nobis September 30, 2016 report, pg. 21, next-to-last paragraph) that pumping interference is likely to occur between the proposed PWS (Public Water Supply) wells. Also, interference between the proposed PWS wells and existing residential wells cannot be ruled out.

3.3 Nitrogen Loading

The NGI Report, Section 2.3.1 and Appendix A contain an extensive discussion of the drawbacks of the nitrate mass balance calculations (as defined by "Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading, 310 CMR 15.216", dated 2/22/16 (Guidelines)) and the merits of dispersion analyses. Although Nobis agrees that the relative drawbacks and merits of both methods are debatable, Nobis considers that in the broad sense, the two methods are both over-simplifications and both are of potential value if interpreted with consideration of each method's underlying assumptions and limitations.

Nobis points out the following general points for the ZBA's consideration:

- Nobis' purpose in performing nitrate mass balance calculations according to the Guidelines was to provide the ZBA with information, not to specifically address Title 5 compliance or lack of compliance. The method described in the Guidelines was used by Nobis, not because it predicts nitrate concentrations at a point (it does not), but because it is a standard, widely used, detailed method, whose results could be checked by others. Other, more site-specific nitrate mass balance calculations could be performed for the Site, but were not, because of the availability of this standard method. Also, more robust analytical and numerical modeling approaches are available, but would have required more field investigations and data than were available.
- NGI's assertion that the nitrate mass balance calculation only applies if credit land (***Section 2.3.1, 1st & 2nd paragraphs)*** is proposed appears not to be consistent with the Guidelines. The Guidelines state, on page 9, that "Where the proposed discharge from a facility is 2,000 gallons per day (gpd) or greater, but less than 10,000 gpd, and may impact sensitive receptors, the Approving Authority may require a site-specific mass balance analysis …". According to the NGI report, the Title 5 flow rate is 6,380 gpd, clearly within the 2,000 – 10,000 gpd range. Past correspondence with MassDEP (Brem 309) indicates that MassDEP will consider the SDAs for this project as a single septic system. Nobis' studies in 2015 and 2016 have shown that the proposed discharges may impact sensitive receptors (either the proposed PWS wells or existing homeowner wells). Because all conditions listed above are met, it appears that the Approving Authority may require a nitrate mass balance analysis, although this was not the reason why Nobis performed the analyses.
- Both the nitrate mass balance method and the dispersion analysis method represent major simplifications of the physical processes that are expected to affect effluent to be discharged at the Site:
    - Each method represents an over-simplification of a complex natural system in soil and groundwater.
    - Each method necessarily depends on theoretical assumptions that, at best, are only approximately true at the Site.
    - Each method is only as good as its input parameters. In the present case key input data are lacking, especially for the relocated SDA2. Questions regarding groundwater flow directions in the vicinities of SDA2 and SDA1 remain, although knowing the groundwater flow direction is critical for both methods.
- Both methods produce results that are useful if interpreted with the method's limitations in mind, allowing comparison in the relative sense, from one portion of the Site to another. Mass balance results (i.e. nitrate concentrations) can be compared to other mass balance results, and dispersion results can be compared to other dispersion results, but the nitrate concentrations from the different methods should not be compared to each other.
- Neither method alone considers all the primary processes that may serve to change nitrate concentrations following effluent discharge. For this reason, a more complete understanding may be gained by performing both mass balance and dispersion calculations.
    - The mass balance method primarily considers only dilution due to recharge and ignores other key physical processes.
    - The dispersion method considers diffusion (in three dimensions) and advection, but does not consider dilution.

- Both methods are “conservative” and do not consider possible breakdown of nitrates in soil or groundwater. (Non-conservative versions of dispersion analysis are available.)
- Both methods consider nitrates only and do not consider other processes that may affect the concentrations of bacteria, viruses, or other effluent constituents.
- Neither method addresses heterogeneously fractured bedrock, in which all existing and proposed wells are installed.

Nobis offers the following incomplete list of strengths and weaknesses of the nitrate mass balance method detailed in the Guidelines and used by Nobis in 2015 and 2016:

- Consideration of dilution by recharge to groundwater is a strength, but use of a statewide average for recharge instead of a Site-specific value is a weakness.
- Dependency of the resulting nitrate concentration on a delineated Area of Impact (AOI) is a weakness unless a reasonably complete set of groundwater elevations allows the creation of a good groundwater contour map for determining groundwater flow directions.
- Different results are obtained by the same size rectangular leachfield, depending on how it is oriented relative to groundwater flow direction. NGI ***(Section 2.3.1, p. 4, next-to-last paragraph and Appendix A, Figure 4)*** considers this a weakness of the method, but Nobis considers it a strength. A proposed SDA oriented transverse to groundwater flow should be expected to impact a wider area but with lower concentrations of nitrates than an SDA whose long axis is parallel to the groundwater flow direction and presents a narrower “front”.
- The down-gradient boundary of the AOI is a property line or sensitive receptor, but the result represents a relative average nitrate concentration within the AOI. The method is vulnerable to mis-interpretation, in which it might appear that the result of the calculation represents a predicted concentration at the receptor or down-gradient AOI boundary.
- The mass balance method does not consider fractured bedrock and thus cannot be used to predict nitrate concentrations in a bedrock well. An exception might occur for an improperly grouted well or for a well that is not sealed in competent bedrock. If such a well were located in an area where overburden groundwater has elevated nitrates, this groundwater might seep down the outside of the well casing and enter the well.
- Nobis agrees with NGI that because the mass balance method ignores diffusion, it fails to account for lateral spreading of nitrates outside of the side boundaries of the AOI. However, Nobis questions whether this effect is any more significant than the approximation required in locating the side boundaries based on sparse water level data and generalized groundwater contour and flow direction maps.

Nobis offers the following incomplete list of strengths and weaknesses of the dispersion method used by Nobis in 2015 and by NGI in its August 8, 2016 report:

- Consideration of advection and diffusion, key physical processes ignored by the mass balance method, is a strength of the dispersion method.
- Lack of consideration of dilution may be a weakness.
- The ability to predict a nitrate concentration at a point rather than an average concentration for an area is a strength. However, the results only apply to overburden groundwater, not to bedrock groundwater or to a bedrock well, unless the well has faulty construction, as noted above.
- Predictions of nitrate concentrations are highly sensitive to model parameter values that are often, and specifically in the Long Ridge Road project analysis to date, based on either

the average of a small number of field measurements or standard reference material values. Small errors in parameter estimation can result significant over and/or under predictions of concentrations depending upon the magnitude and direction of the parameter value error. Some of these variables are mitigated by use of a long time period (30 years used by Nobis and NGI), which allows equilibrium to be reached.

- Specifically, knowledge of the groundwater gradient is needed for the dispersion method, but not for the mass balance method. For the Site, groundwater gradients can be determined only from a contour map that is constructed based on water level measurements at only five monitoring wells. An assumption that the groundwater potentiometric surface parallels topography is necessary to construct the map; the resulting uncertainties impact the reliability of the dispersion analyses. This is especially true for proposed SDA2, where there are no direct groundwater level measurements and SDA1, where it is unknown whether the groundwater flow direction is eastward, southward, or both.
- The dispersion method applies to flow lines, not areas, and is most accurate for flow lines that coincide with the center line of a plume (which is usually in the direct groundwater flow direction, if this is known). For flow lines that are oblique to the center line of the plume or where groundwater flow direction is uncertain, there is less confidence in the predicted nitrate concentration.
- The use of non-site-specific parameter values (especially for dispersion analyses associated with re-located SDA2) provides predictions of nitrate concentrations at point locations in overburden groundwater which may not be suitable for assessing human health effects based on not-to-exceed values.

The NGI Report, Section 2.3.1, 5th paragraph on p. 4, states that consideration of groundwater seepage velocity by the dispersion method is a major advantage of this method, compared to the mass balance method, which does not consider seepage velocity. NGI presents a sample calculation showing that within one year of the start of the discharge, the groundwater plume created by the discharge will extend nearly 1,000 feet in the down-gradient direction, far beyond the AOIs delineated by Nobis for the Site. NGI asserts that this means that the nitrate concentration within the AOI would be reduced because a significant mass of nitrate would move beyond the AOI in just one year. This would be true for a one-time release of nitrate from the proposed SDA. However, since effluent with an assumed nitrate concentration of 19 milligrams per liter will be discharged continuously, nitrate will be supplied to the system, at the SDA, effectively replacing the nitrate mass that may exit the down-gradient boundary of the AOI.

Further, NGI used a high groundwater gradient of 0.10, higher than all but one of the gradients used by Nobis in our May 1, 2015 Report or by NGI in their August 8, 2016 Report. The resulting groundwater seepage velocity of nearly 1,000 feet per year is probably unrealistically high for most portions of the Site. The average gradient for Nobis' twelve dispersion calculation flow lines is about 0.045. The average gradient would have been a more appropriate value for NGI to use in its example seepage velocity calculation.

The NGI Report, Section 2.3.2, p.4, last paragraph and Appendix A, Figure 3 compares contoured nitrate concentrations (obtained by the dispersion method) to the layout of an AOI (delineated by the mass balance method) from proposed SDA2 and concludes that the mass balance method over-estimates the nitrate concentration for the AOI. Nobis believes that this is not a reasonable comparison, because the mass balance method does not attempt to estimate a

nitrate concentration at any particular point (and therefore is not subject to contouring), but the method estimates a mass balance average for an area. Further, the mass balance calculation result cited by NGI from Nobis' September 2016 Report included the input from the existing septic system on the Site, whereas the dispersion results that are contoured appear not to have included this input.

The NGI Report, Section 2.3.2, p.5, next-to-last paragraph of section, discusses the Carlisle Board of Health requirement for a three-dimensional model such as ModFlow and states that the mass balance approach is not a three-dimensional model, and the dispersion analysis approach is three-dimensional. Nobis agrees that the mass balance approach is not three dimensional. The dispersion analyses that have been performed by Nobis and NGI for the present project have three dimensional elements in that they include vertical and lateral diffusion as well as down-gradient diffusion and advection, but otherwise only calculate dispersion at a point on a map and are not fully three-dimensional in the way that a ModFlow model is three-dimensional. If a ModFlow three-dimensional model were constructed for the Site, additional field data would have to be gathered for model inputs and calibration.

3.4 Hydraulic Connection Between Overburden-Bedrock

The NGI Report, Section 2.3.2.1 suggests that refusal reached at MW-4 and MW-5 could be due to basal till. However, the drilling logs for these wells (NGI March 2015 Report, Appendix A) identified weathered bedrock from cuttings, underlain by refusal interpreted as competent bedrock. Nobis believes that it is unlikely that basal till underlies weathered bedrock and represents refusal at these locations. However, it is possible that the material interpreted as weathered rock is actually basal till. (Because augers were used, blow count comparisons with the other borings are not possible.) Because of the critical nature of the MW-5 location near the proposed Public Water System wells, Nobis believes that characterizing the overburden/bedrock interface in this area is important.

The NGI (December 23, 2016) Report criticizes Nobis for not attempting to drill in this area. Nobis did recommend drilling in this area, but permission to do so was denied by the Applicant.

Finally, NGI questions the need for additional soil borings based on Nobis claim (as worded by NGI) that the presence of basal till at SDA2 and SDA3 "did not resolve the potential impacts from discharges at these locations." Nobis wishes to clarify that the borings at SDA2 and SDA3 provide encouragement that overburden and bedrock groundwater are not hydraulically connected at these locations. The concern comes from the likely possibility that the clay layers and/or basal till layers beneath these locations do not extend far enough to prevent infiltration of impacted groundwater into bedrock fractures that possibly connect to existing or proposed wells.

The NGI Report, Section 2.3.2.1, last paragraph and Figure A show expected nitrate concentrations at a depth of 11 feet (presumed top of bedrock), varying with distance from a proposed SDA. Nobis cannot evaluate these calculations and graphs, because the input parameters, particular assumptions, and specific procedures used to obtain the results are not presented. Nobis questions whether, since it requires 80 feet in the down-gradient direction for nitrate concentrations to reach their maximum at a depth of only a few feet below the bottom of the Septic Disposal Area, wouldn't it also predict that lateral dispersion across an AOI side boundary would amount to only a few feet for every 80 feet of AOI downgradient length.

3.5 Water Quality Data

The NGI Report, Section 2.3.2.3, first three paragraphs, cites low nitrate results for the wells at 90 Long Ridge and 100 Long Ridge (the existing well at the Site). These results are encouraging, but the 90 Long Ridge result does not indicate that overburden and bedrock groundwater are disconnected. This is because the well was an overflowing artesian well when drilled, indicating an upward gradient from bedrock to overburden groundwater. This upward gradient would inhibit infiltration of impacted groundwater downward into bedrock, even if there were no basal till at this location. With a PWS field only a few hundred feet away and drawing a volume of water equivalent to 20 homes, the well may no long retain artesian characteristics if the proposed project were to become operational.

This leaves only the 100 Long Ridge result as an indicator of the lack of hydraulic connection between overburden and bedrock groundwater. This finding is consistent with the finding of dense till in boring B2. The well that serves the existing home is upgradient of the existing septic system. The well is probably side gradient, from the existing manure pile, whose presence, coupled with lack of nitrate in the well, is cited by NGI as evidence that the Site can accept a large nitrate load without impacting bedrock groundwater. Nobis explained our opinion as to why the manure pile may not be a good analog to the proposed septic system, in our Technical Memorandum dated December 8, 2016. The lack of nitrate in the 100 Long Ridge well is undoubtedly a good finding for the current conditions, but Nobis believes that it is unreasonable to conclude that no existing or proposed well will be impacted by the project based on the result for this one well (100 Long Ridge).

The NGI Report, Section 2.3.2.3, last paragraph includes a partial quote from Nobis' Technical Memorandum dated December 8, 2016. NGI omitted a key final phrase (underlined here) from its Nobis quote: "The nitrate results from wells in the area 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, <u>with the current development density</u>."

4.0 CONCLUSIONS

Nobis believes that when interpreted in the light of the method limitations and the quality of input data, both the nitrate mass balance approach and the dispersion method are useful in assessing potential impacts of the proposed development to overburden groundwater. Nobis believe that results of both methods are relative and can be compared to other results obtained with the same method but not with results obtained by the other method. Given that Nobis has advocated using the two methods together, Nobis accepts NGI's suggestion (last paragraph of Section 2.3.1) that the dispersion results could be emphasized to a similar degree as the mass balance results. Nobis disagrees that the mass balance results are not applicable to, or helpful in assessing the impacts of, this project. These analyses provide information regardless of their requirement (or not) for Title 5.

Even if consensus is reached, and additional Site data were obtained, improving the results obtained by these two methods, the chances that impacted groundwater might travel in bedrock fractures and reach an existing or future bedrock well remain largely unknown. Most of the discussion above and in NGI's report addresses overburden groundwater only. Nobis believes

that at the level of development and effluent discharge proposed and for the new wells proposed to be drilled, present information does not allow a conclusion that all existing and proposed water supply wells will be safe from impact

We have enjoyed working with you and the Town on this project. Thank you for the opportunity to be of service. If you require additional information, please do not hesitate to contact us at (603) 224–4182.

Very truly yours,

Nobis Engineering, Inc.

James H. Vernon, Ph.D., P.G.
Senior Hydrogeologist

Cc: Chris Heep