September 30, 2016
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: Phase 4 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) 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 (a.k.a. "The Birches") in Carlisle, Massachusetts ("Site"). (See Figure 1.) 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 the primary 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. (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.)

This letter report is the primary deliverable product under Amendment 5.

1.0 INTRODUCTION

Nobis understands that the 9.84-acre Site is undergoing 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 whose significant differences from the original proposal include:

- Instead of a series of private wells intended to serve the proposed new homes, the Applicant is now proposing to create a new Public Water System (PWS) that will be served by seven proposed wells, located on either side of a brook in the eastern portion of the Site.

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- Proposed Septic Disposal Area (SDA) 2 has been moved from its original location adjacent to SDA 3 in the northwestern corner of the property to a new location along the western property boundary of the Site, approximately 350 feet south of its former proposed location. (Proposed SDAs 1 and 3 are in approximately the same locations as in the Applicant's 2015 proposal.)

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).

Phase 4 includes 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.

Nobis' work in Phase 4 does not include additional field investigations, but new modelling and other calculations related to the Site are included. Although a full peer review or critique of a new hydrogeological report (Northeast Geoscience, Inc. (NGI) 2016 Report; Brem 297 08-08-2016) submitted by the Applicant was not included in Nobis' Scope of Work for Phase 4, discussion of that report, as it relates to Nobis' objectives stated above, is included (Section 3.0). Similarly, a detailed evaluation of the feasibility or permittability of the proposed PWS is not one of Nobis' objectives, but aspects of the proposed PWS are discussed (Section 4.0), as these pertain to evaluating the potential impacts listed above. PWSs are regulated primarily by the Massachusetts Department of Environmental Protection (MassDEP), so primary responsibility for reviewing PWS permitting applications does not belong to the Town.

2.0 BACKGROUND

The Applicant submitted a 40B housing approval application (Brem 001 07-03-2014) to the Town on July 2, 2014. In 2015, Nobis submitted a Phase 1 report (Brem 172 02-20-2016), a Phase 2 Report (Brem 212 05-01-2015), and a Phase 2 Addendum (Brem 224 05-20-2015) in 2015, in which Nobis presented hydrogeological information, integrated Nobis' investigation results with investigation results by the Applicant, and assessed potential hydrogeologic impacts of the proposed septic systems and new private wells.

Following conditional approval of this application by the Town in August 2015 (Brem 290 08-12-2015), the Applicant appealed to the Massachusetts HAC, seeking relief from some of the conditions. A mediation session with a mediator assigned by the HAC occurred in March 2016. The Applicant submitted a new plan (Brem 291 07-08-2016, later revised (Brem 303 08-25-2016, Attachment A). The revised plan calls for changes listed above and explained in the NGI 2016 Report (Brem 297 08-08-2016) and in a letter from the Applicant to the Town dated August 23, 2016 (Brem 304 08-25-2016).

The revised plan calls for a PWS to be served by seven drilled wells, located on either side of a brook in the eastern portion of the property and separated from each other by at least 50 feet. The new wells will have 100-foot-radius Zone I Wellhead Protection Areas (Attachment A). the new PWS wells are generally located down-gradient, relative to likely overburden groundwater flow directions, from proposed SDAs 2 and 3 (Figure 1). According to the Applicant, each well will need to produce 0.63 gallons per minute (gpm), for a total of 4.43 gpm for the seven wells (Brem 304) or about 6,380 gallons per day (gpd). (See Section 4.0 for discussion.) The Applicant proposes (Brem 304) to include a storage tank with the capacity for two days of water usage; Nobis assumes that this capacity would be approximately 12,700 gallons. Nobis understands that the existing well that serves the present house will be used for irrigation. Neighboring homes, including abutters, are served by existing bedrock domestic drinking water wells (Figure 2).

The revised plan calls for the same number of homes (19 new homes plus the existing 4-bedroom home) and the same total number of bedrooms (58) as proposed in 2015, but the styles and locations have been altered, as have the assignments of the different homes to the proposed SDAs (Attachment B). The three proposed SDAs will be designed to service 18 bedrooms each. The existing 4-bedroom home will continue to be served by the existing septic system. The required design flows for each Septic Disposal Area depend on whether a design rate of 110 gpd or 165 gpd per bedroom is used. The 110-gpd rate follows Massachusetts Title 5 regulations and is used by the Applicant; the 165 gpd rate is required by the Town of Carlisle. Design flows for each proposed SDA and for each rate are shown in a table in Attachment B. (Nobis notes that for the 110 gpd per bedroom rate the total design flow for the septic systems is 6,380 gpd, slightly more than the proposed total design flow for the PWS.)

Nobis completed Phase 1 of an independent hydrogeologic study and submitted a Phase 1 Report, dated February 20, 2015 (Brem 172 20-20-2015). In the Phase 1 study, Nobis reviewed background hydrogeologic information and submittals to the Town regarding the project between July 2014 and February 2015. Nobis observed general Site conditions and topography, bedrock outcrops, and well locations during a Site walk on January 23, 2015. Nobis also conducted a photolineament analysis, which indicated that several weak but persistent photolineaments are present in and around the Site; the most prevalent photolineament orientation is northwest-southeast.

NGI submitted a hydrogeologic report entitled "Groundwater Impact Analysis, Brem Property, 100 Long Ridge Road, Carlisle, MA", dated March 25, 2015 (NGI 2015 Report; Brem 193 03-25-2015). This report included the results of monitoring well drilling, water level measurements, slug tests (to estimate hydraulic conductivity), groundwater mounding estimates, a mass balance nitrate loading model for the site (under current conditions and proposed, post-construction conditions), a nitrate solute transport model, and water quality data for the existing home on the Site and the new home at 90 Long Ridge Road.

Nobis submitted a Phase 2 Report, dated May 1, 2015 (Brem 212 05-01-2015) and a Phase 2 Addendum Technical Memorandum, dated May 20, 2015 (Brem 224 05-20-2015). These reports documented a bedrock geology investigation and hydrogeologic conceptual site model, groundwater mounding analysis for the proposed septic disposal systems, nitrate loading and mass balance calculations, nitrate dispersion analyses, and recommendations for additional study. (See Section 6.0.)

Discharge of wastewater to the Proposed SDAs will create groundwater mounds whose predicted height depends on model assumptions and inputs. For the 2015 proposed project, Nobis estimated that after 90 days of discharge and using site-specific hydraulic conductivity, Applicant-designed discharge of 1,980 gpd for each Area, and other input parameters, maximum mound heights of 0.70 feet and 1.53 feet above the existing water table are predicted for Area 1 and Areas 2 and 3 combined, respectively (see Phase 2 Report). These groundwater mounds will increase groundwater gradients and flow velocities and may create radial flow in the immediate vicinities of the proposed SDAs, but probably do not significantly alter the groundwater flow directions at the Site scale.

For the 2015 Phase 1 and 2 studies, nitrate mass balance analyses and nitrate dispersion analyses along selected flow lines to property boundaries and sensitive receptors predicted overall average nitrate concentrations and location-specific concentrations. As with any modelling, the accuracy of these predicted concentrations depends on the simplifying assumptions inherent to the model and on the accuracy of the input values. With these cautions in mind, the mass balance results indicated that there may not be sufficient dilution to reduce nitrate concentrations below 10 milligrams per liter (mg/L) on the average, at some property lines and proposed (in 2015) wells. Dispersion analyses also predicted that at the site boundary to the northeast of Proposed SDAs 2 and 3 (adjacent to each other in the 2015 plan), nitrate concentrations would be greater than 10 mg/L. Nitrate concentrations above background levels but below 10 mg/L were predicted at proposed and existing well locations. These predictions apply to nitrate concentrations in overburden groundwater, not in bedrock groundwater, nor are they directly comparable to the concentrations predicted by the mass balance approach.

3.0 PROPOSED PUBLIC WATER SYSTEM CONSIDERATIONS

The proposed PWS shown on" Plan P – Public Water System" (Attachment A) and as explained in the NGI 2016 report (Brem 297 08-08-2016) provides the qualitative "improvement" of moving water supply wells for the project farther away from the proposed SDAs than the private wells shown in the 2015 plan. Also, the PWS will be permitted (or not) by the MassDEP and regulated in the future by the MassDEP, rather than the Town. Information regarding the PWS available to Nobis is conceptual only, and providing a full review of the proposed PWS is outside of Nobis' scope. However, Nobis has been asked by the Town to comment on certain aspects of the proposed PWS that may influence the assessments that Nobis is conducting.

MassDEP's "Guidelines for Public Water Systems", dated April 2014 (PWS Guidelines) states that "The system, including the water source and treatment facilities, shall be designed for maximum day demand at the design year" (PWS Guidelines, p. 2-2). Nobis has not researched the specific requirements for determining the maximum day demand for a new Public Water System, but this demand may be different from the 6,380 gpd (4.43 gpm, sustained over 24 hours), identified by NGI (2016) as the Title 5 flow rate for the proposed development.

The Applicant has assumed that each of the seven wells will produce one-seventh of the Title 5 flow (or, presumably, whatever the required flow for the 20 homes and 58 bedrooms is). Whether each well can sustainably produce this amount of water will not be known until the wells are drilled and subjected to pumping tests. It is possible that one of more of the wells may be "dry holes", while other wells are capable of producing more water than needed. It is also more likely than not that two or more of the wells will interfere with each other when pumped (see Section 6.0).

Wells 4 and 5, and possibly Wells 6 and 7, are located on or near bedrock outcrops located east of the brook. For drilling rig access or due to well yield considerations discussed above, some of the wells may be moved from their presently planned locations. This would result in correspondingly moved Wellhead Protection Area Zone Is; see below for implications. If any of the wells are located within 50 feet of each other, MassDEP will combine their yields when determining the size of the Zone I area. Only a 10% increase in well yield would result in an increase in the Zone I radii to greater than 100 feet around each well, per PWS Guidelines, Appendix D. (See Attachment D in this report.) If the wells are located at distances greater than 50 feet from one another, then MassDEP will determine which wells, if any, are to be assigned combined yields, per PWS Guidelines, Chapter 4.

According to the PWS Guidelines (p. 4-11), "The Surface Water Treatment Rule (SWTR), an amendment to the federal Safe Drinking Water Act, requires MassDEP to inform the U.S. Environmental Protection Agency of groundwater sources determined to be under the direct influence of surface water" (GWUDI), as these may be at risk of carrying water-borne pathogens. The PWS Guidelines further state (p. 4-62) that new PWS wells must either receive a MassDEP SWTR exemption or be considered as surface water sources. In order to receive an automatic exemption without further testing, a bedrock well serving a Community Water System (which the proposed PWS would be, because it serves residences), it must be more than 50 feet in depth, have a surface water seal, and be located 200 feet or more from surface water. Because the wells, as planned, will be less than 200 feet from the brook, they should not be expected to receive an automatic exemption (p. 4-63).

Because the proposed wells will probably fail to receive an automatic exemption, they will be subject to further testing in the first year of operation and possibly beyond. In anticipation of this future testing, the PWS Guidelines (p. 4-14) recommend that a microparticulate analysis (MPA) be conducted at the end of the pumping test for the new wells. While it is likely that the proposed wells will eventually receive exemptions from the SWTR, this is not guaranteed. The consequences of the wells receiving a determination of GWUDI might require the construction of a water filtration plant, which would likely be prohibitively expensive.

Pumping the proposed well may or may not impact wetland hydraulics and flow in the brook; Nobis is not aware of boring logs or other information that might indicate whether the wetland is perched or is in hydraulic communication with groundwater in the overburden or bedrock. This question is discussed in Section 6.0. Also, and as acknowledged by the Applicant, a wetland permit will be required for such activities as building a well access road and drilling the wells. Care should be taken during drilling and pumping tests so that water discharged from the wells does not directly enter the brook or wetland or cause soil erosion near the wetland or brook.

Wells that service a PWS are subject to wellhead protection. This involves several requirements, including the delineation of Wellhead Protection Area zones, including the "protective radius" known as Zone I (PWS Guidelines, p. 4-31). For the proposed wells, the Zone I radii will be 100 feet and will form a composite area, as shown on the Applicant's Plan P (Attachment A) and on Figures 1, 2, and 3 in this report. A larger area, Zone II, is not shown, and an Interim Wellhead Protection Area (IWPA) may be required. The PWS Guidelines (Appendix D) provide a formula for calculating the radius for the IWPA. Zone II is delineated as the land area from which contaminants could potentially reach a PWS well. Zone II is generally required for PWS wells but does not take effect until the Zone II delineation is approved by MassDEP. For PWS wells that do not have an approved Zone II, a circular IWPA is used for wellhead protection.

For the 6,380 gpd (4.43 gpm) design flow indicated by NGI, the IWPA radius would be about 542 feet, if the combined flow of the wells is assumed to equal the design flow and the wells are considered as a single source. NGI (2016 Report; Brem 08-08-16) states that each well would have an individual yield of 0.63 gpm; if the IWPA radius is calculated based on the individual well yields, the radius for each well would be about 420 feet. In either case, the IWPA would occupy a large portion of the Site. This means that the Site would likely be classified as a Nitrogen Sensitive Area (Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading, p. 3) and therefore would require that no more than 440 gpd of wastewater discharge per acre would be allowed.

Based on a discussion with a staff member at MassDEP Headquarters, the composite Zone I area cannot be counted as acreage for meeting the 440 gpd per acre standard, if the design flow for the septic system is greater than 2,000 gpd. The MassDEP cited Title 5, 310 CMR 15.216(3), but stated that the final decision would be made in the Regional Office when a Title 5 application is reviewed. The cited portion of the regulation states: "Land located within a Zone I of a public water supply well may be used as nitrogen credit land unless … the proposed design flow is 2,000 gallons per day or greater." Nobis understands, based on a letter from MassDEP (Brem 309 09-08-2016), that the three proposed SDAs will be considered a single septic system with flow greater than 2,000 gpd. Assessing whether or not any permit should be granted is outside of Nobis' scope, but it is clear that water supply considerations, including maximum daily demand, well location, and IWPA radius can have significant implications for some of the impacts that Nobis has been asked to evaluate. Nobis recommends (Section 8.0) that the Town seek to clarify these matters early in the process of evaluating the Applicant's revised proposal.

4.0 NGI 2016 REPORT

NGI. submitted a report entitled "Wastewater and Water Supply Design Modification Impacts", dated August 8, 2016 (Brem 297 08-08-2016), in which hydrogeologic and other impacts related to the 2016 modified 40B proposal were addressed. The report described briefly the Public Water System (PWS), proposed to replace the series of private wells that were proposed in 2015 (see Section 3.0); presented the results of new nitrate dispersion analyses conducted by NGI; and briefly discussed groundwater mounding. Maps showing the proposed PWS and flow lines and receptors for the dispersion analyses were included. The report also included results of a hypothetical exercise to show the conceptual decrease in nitrate concentration with distance from an imaginary septic system, based on dispersion calculations. A critique or peer review of the report is outside of Nobis' scope and objectives, but the Town has requested that Nobis comment on aspects of the NGI report that are relevant to Nobis' impact assessment.

No new field investigations, measurements, or data were reported by NGI. The analyses consisted of new modelling using existing data and based on the new plan (Plan P – Public Water Supply, dated February 2, 2016 (Attachment A)). No test pits, borings, or monitoring wells in the vicinity of relocated, proposed SDA 2 were reported, and no new water level measurements were reported. (One exception may be the hydraulic conductivity value of 8.23 ft/day for Area 2 (see Line 16 in Table 1C), also used for some of the lines from Area 3, for nitrate dispersion. The derivation of this value is not explained.) The lack of new data means that 2015 data must be used, and assumptions or guesses regarding characteristics for the re-located Area 2 are necessary.

The NGI report also offers an opinion as to the applicability of the Town's requirement that nitrate concentrations at a down-gradient property line be 5.0 milligrams per liter (mg/L) or less, using the hypothetical calculations described above. The report distinguishes between a property line and a drinking water well, pointing out that the latter is a sensitive receptor and the former is not a receptor; the report concludes that applying the criterion to a property line for "the proposed wastewater disposal areas would seem nonsensical." The report argues that violating the property line compliance requirement "does not mean that the concentration will be exceeded at an abutting private well."

Nobis agrees that violating the 5.0 mg/L level at a property line does not necessarily mean that the concentration will be exceeded at the abutter's well, but points out that violating the compliance requirement at the property line also does not assure that the concentration will be below the limit at an abutting private well. One can envision a scenario in which predicted nitrate concentration is 8 mg/L at a property line and 6 mg/L at a down-gradient well. More importantly, if nitrate concentrations are predicted for the overburden and the wells in question are bedrock wells, a wide range of possibilities exist. Nobis considers that requiring (or not) the 5.0 mg/L or less nitrate concentration at a property line is a question of policy, not of science.

The NGI report also advocates that nitrate mass balance/loading calculations as specified by Title 5 Guidelines might be used to determine if a proposed land use would result in an increase or decrease in overall nitrogen load at a site. Also, the calculations might be used to evaluate compliance with a "credit land" approach, as described by Massachusetts Title 5 regulations. However, NGI states that the "results of the analysis should not be considered predicted nitrate concentrations" at specific locations.

Nobis agrees that nitrate concentrations determined by the mass balance method outlined in MassDEP Guidelines (Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading, 310 CMR 15.216, dated 2/22/16) are not predictive of nitrate concentrations at a given location, except in a relative sense. However, the mass balance calculations provide useful information, obtained by a standardized method that is based on different physical processes than the processes that are modeled by dispersion analysis. Taken together, the two approaches can identify areas where impacts to groundwater due to septic discharges are likely to be greater or lesser. Finally, both methods address potential impacts to overburden groundwater, while neither method can predict potential impacts to bedrock groundwater, unless there is a direct hydraulic connection between overburden and bedrock groundwater at the Site. Nobis believes that nitrate mass balance calculations, when interpreted with caution, are useful and are presented below (Section 5.0).

NGI's nitrogen dispersion results were slightly lower than, or equal to, the Nobis results presented in the 2015 report, for flow lines that were similar or identical to Nobis' flow lines. High nitrate concentrations were predicted for flow line 7 (17.85 mg/L), from proposed SDA 3 to the northeast property line (see Attachment C) and for flow line 12 (8.53 mg/L), from proposed SDA 3 to the western property line. All other NGI results, including for flow line 16, from proposed SDA 2 to the brook, are less than 5.0 mg/L.

Nobis notes that the new NGI calculations are based on flow lines that are consistent with the overburden groundwater potentiometric surface ("water table") contours interpreted by Nobis in our Phase 2 report (2015). NGI appears to accept that the potentiometric surface probably roughly parallels topography, unless site-specific data indicates otherwise. This means that groundwater may flow northeastward, off site, from the vicinity of SDA 3. Also partial radial flow may occur from SDA 1, although there is little water level data in this area.

The NGI report discusses groundwater mounding over the proposed septic disposal systems but does not present any new results. The report makes qualitative predictions that the groundwater mound in the northwestern part of the site (proposed SDA 3) will be lower than under the plan proposed in 2015, which had SDAs 2 and 3 adjacent to each other in the northwestern corner of the property. The report also predicts that a new mound will be created in the west central part of the Site, due to relocated SDA 2. (See Section 5.0 for the results of Nobis' new mound height calculations.)

Finally, NGI characterizes Carlisle's requirement that water table rise associated with mounding must be 0% (or may be revised to a 2% rise) is "unreasonable and … arbitrary." NGI points out that mathematical models of groundwater mounding typically cannot produce a mound height of zero at any distance. Nobis agrees that groundwater models will not predict a mound height of zero in any down-gradient direction.

5.0 MOUND HEIGHT CALCULATIONS

The objective of groundwater mounding analysis is to estimate the height of a water table mound that is expected to form beneath the proposed new SDAs designed by the Applicant for the 19 new homes. Mounding analysis is an important component of the assessments Nobis has been asked to perform because if the predicted mound height is high enough, this can change the interpreted groundwater contour map (Section 6.0). If the changes in contouring are sufficient, this in turn can cause changes in the interpreted groundwater flow directions, which in turn affects the delineation of Areas of Impact (Section 7.2) for mass balance calculations. Also, if dispersion analysis calculations are performed, the groundwater gradient value needed for the equation is determined from the contour map. For permitting under Title 5 (outside the scope of this report), mound height analysis is required for septic systems with design flow of 2,000 gpd or greater (MassDEP Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading).

Nobis conducted separate mound height analyses for each of the three proposed SDAs, using length and width dimensions for each proposed area as shown on the Applicant's Plan P – Public Water Supply (Attachment A). The Applicant has assigned the proposed new homes to the three proposed SDAs so that each are will receive flow from a total of 18 bedrooms (Attachment B). The existing septic system at the Site will continue to serve the existing 4-bedroom house; Nobis did not perform a mound height calculation for this existing system.

The mound height was estimated using a web-based mounding program by Aqtesolve: http://www.aqtesolve.com/forum/rmound.asp. This program is intended for a rectangular loading area (leachfield) and is based on an equation developed by Hantush (1967). The program assumes that the aquifer is a porous medium, is infinite, is unconfined, is homogeneous and isotropic, and has a flat potentiometric surface. The program calculates a single result for the maximum mound height but does not produce a contour map of the predicted mound. The resulting predicted mound height can be checked against depth to seasonal high water table to predict whether compliance with vertical separation requirements (either 4 or 5 feet between the bottom of the SDA and the seasonal high water table, depending on whether advanced technology is used in the septic system design, per Title 5; 310 CMR 15.212) will be achieved. The program is recommended by the MassDEP.

As with any groundwater model or simulation, the actual groundwater mound that will form over a leachfield may differ from the estimate provided by the program, depending on the degree to which the assumptions are violated and on the accuracy of the input parameters to the program. For input parameters, Nobis used site specific values obtained from the NGI 2015 report for proposed SDAs 1 and 3. There are no reported borings, monitoring wells, slug tests, or test pits at the relocated SDA 2; Nobis used values averaged from SDAs 1 and 3 as inputs for Area 2, except where noted.

Nobis conducted two sets of mound height calculations: the first set assumed the Applicant's design flows of 1,980 gpd (based on 110 gpd per bedroom) for each proposed SDA; the second set assumed the Town's recommended design flows of 2,970 gpd (165 gpd per bedroom) for each disposal area. For each of these discharge rate scenarios and disposal areas, Nobis calculated mound heights for durations of 90 days and 180 days (these durations are recommended by MassDEP). For each calculation for Areas 1 and 3, Nobis used a saturated thickness that is the arithmetic average of values provided by NGI for the two monitoring wells at each location on February 13, 2015 (NGI 2015 Report, Appendix B). For Area 2, Nobis averaged the saturated thicknesses reported for MW-1-15, MW-1A-15, MW-2-15, and MW-2A-15. Finally, Nobis calculated the mound heights using two different hydraulic conductivities – the Site wide geometric mean of 9 ft/d and the Area-specific conductivity obtained by averaging (arithmetically) the slug test results for wells at the specific areas. For Area 2 the Area-specific conductivity used was obtained from the NGI 2016 report (Brem 297), Table 1C (although NGI did not provide an explanation for this value). The mound calculation inputs used by Nobis are summarized below and presented in Table 1.

5.1 Inputs:

The following input parameters were used in the calculation:

- Length and width of loading areas: obtained from Applicant's Plan P – Public Water Supply (Attachment A)
- Loading volume: 1,980 or 2,970 gallons per day for each Area
- Loading rate: calculated by converting Loading Volume in gallons per day to cubic feet per day and dividing by the area of the leachfield for each Area
- Saturated thickness: averaged for Areas 1 and 3 from slug test results for that specific Area (see above); saturated thickness for Area 2 assumed to be the average of the values used for Areas 1 and 3
- Hydraulic conductivity: averaged for Areas 1 and 3 from slug test results for that specific Area (see above); value for Area 2 from NGI 2016 Report (Brem 297), Table 1C
- Specific yield: 0.195 (average of values for silt and for fine sand (Fetter, 1988, page 74)
- Duration: 90 days (low end of MassDEP recommended range; value requested by Town); and 180 days (high end of range recommended by MassDEP)

5.2 Results:

Monitoring simulation results for different durations are shown in Tables 2 and 3 for the 110 gpd per bedroom (Applicant) and 165 gpd per bedroom (Town) inputs, respectively. Depending on the assumptions used, for Area 1, the estimated mound height (above starting water level) under the Applicant discharge rate varies from 0.74 feet to 1.50 feet. For the Town discharge rate, the estimated mound height varies from 1.09 feet to 2.19 feet.

For Area 2, the estimated mound height with Applicant discharge rates varies from 1.51 to 1.79 feet. For the Town discharge rate, the estimated mound height varies from 2.19 to 2.60 feet.

For Area 3, the estimated mound height with LGH discharge rates varies from 1.59 to 1.91 feet. For the Town discharge rate, the estimated mound height varies from 2.30 to 2.74 feet.

In order to convert mound height to the predicted depth to the top of the groundwater mound (for Title 5 compliance), it is standard practice to use estimated seasonal high water table (ESHWT) as a starting point for a "worst case" assessment. However, no indication of the ESHWT was observed in any of the six monitoring wells drilled at the three proposed SDAs (NGI 2015 Report, p. 2). In this case, NGI calculated ESHWT from test pit observations (NGI 2015 Report, p. 2-3); however, such an estimate can be unreliable because the ESHWT was extrapolated over significant distances. This resulted in ESHWT levels that were lower than actual measured water levels in some of the monitoring wells (NGI 2015 Report, Table 1), a contradiction in terms. Therefore, Nobis used the water levels that were directly measured on January 23, 2015 (NGI Report, Table 1) as the starting water levels to which mound heights were added for SDAs 1 and 3. Nobis used the average of water levels in SDA 1 and 3 for the starting water level for SDA 2.

The following are the results for depth to groundwater after estimating groundwater mounding potential and adding it to the water levels on January 23, 2015:

- Potential depth to the top of the groundwater mound located in Area 1 ranges from 4.44 to 5.89 feet below ground surface.
- Potential depth to the top of the groundwater mound located in Area 2 ranges from 3.26 to 4.35 feet below ground surface.
- Potential depth to the top of the groundwater mound located in Area 3 ranges from 2.34 to 3.49 feet below ground surface.

In order to convert the predicted depths to the top of the mound to relative mound elevations, Nobis added the predicted mound height to the average January 23, 2015 water elevations for the monitoring wells located at the particular proposed Area (Area 1 or Areas 2 and 3, combined). For illustrative purposes on Figure 2, Nobis selected the estimates based on Applicant's loading rate, Area-specific hydraulic conductivity, and 180 days' duration. For Area 1, a mound height of 0.81 feet was added to the groundwater elevation of 103.01 feet to obtain 103.82 feet. For Area 2, the predicted mound height of 1.79 feet was added to the average groundwater elevation obtained by averaging elevations for SDAs 1 and 3 to obtain 108.24 feet, as shown on Figure 3. For Area 3, the predicted mound height of 1.76 feet was added to the groundwater elevation of 113.92 feet to obtain 115.68 feet.

At the Site scale and with a groundwater contour interval of 5 feet, the predicted mound height of 0.81 feet is not enough to alter the contouring around proposed SDA 1. However, the predicted mound increases the groundwater gradient and therefore the groundwater flow velocity. Also, the groundwater mound may encourage radial flow away from proposed SDA 1, at least in the immediate vicinity.

At proposed SDA 3 the predicted mound height of 1.76 feet may cause a noticeable change, at map scale, in groundwater contouring in the vicinity, as shown by red contour lines in Figure 3. These lines are dashed, because they are conceptual and not supported by direct groundwater modeling that extends outside of the SDA. As with proposed SDA 1, increased groundwater gradients and groundwater flow velocities can be expected to result from the mound over Area 3.

For proposed SDA 2, the effects of mounding are somewhat harder to predict, due to the absence of water level data and other information in this immediate vicinity. Although the predicted mound height of 1.79 feet may be sufficient to change local groundwater contours and flow, the confidence in the data and calculations is not sufficient to justify re-contouring in this area (Figure 3).

6.0 HYDROGEOLOGY, GROUNDWATER CONTOURS AND FLOW, AND WETLAND HYDROLOGY

6.1 Summary of Geology and Hydrogeology

Bedrock and overburden geology beneath the Site are described in detail in Nobis' 2015 Phase 1 Report (Brem 172 02-20-2016), Nobis' 2015 Phase 2 Report (Brem 212 05-01-2015), and NGI's 2015 report (Brem 193 03-25-2015). Selected key bedrock geology features, including bedrock outcrop fracture orientations, airphoto lineaments, and bedrock well information, are shown on Figure 2 of the present report. According to the conceptual hydrogeologic model developed in Phase 2, the Site is underlain by sandy glacial till. These overburden deposits (0 to 24 feet thick) are underlain by fractured and variably foliated metamorphic bedrock.

Predominant bedrock fracture orientations are northeast and northwest (Figure 2), with steep dips. The most common trend for fractures observed in the on-Site outcrop is northeast/southwest (NE/SW), with roughly perpendicular fractures that trend northwest/southeast (NW/SE) also present. NW/SE is also the most common photolineament orientation. As described in more detail in Nobis' Phase 2 report, a photolineament is a linear feature observed on an air photo that may represent a bedrock fracture zone. A photolineament is a less direct evidence of a bedrock fracture than an outcrop observation. Because there is essentially no porosity or permeability in the rock matrix, these fractures represent the primary avenues for flow of groundwater within the bedrock. In the overburden, groundwater occurs in the pore spaces within the unconsolidated deposits and flows from areas of higher head to areas of lower head.

Groundwater occurs in both fractured bedrock and in overburden beneath the Site and vicinity; however, overburden is absent where the bedrock outcrops at the surface (east of the brook as shown on Figure 2), and overburden is presumably thin and unsaturated in the immediate vicinity of bedrock outcrops. Groundwater in the overburden is unconfined; no areally extensive clay or other confining deposit is known to be present above the saturated zone in the overburden. The potentiometric surface (unconfined water table) in the overburden ranged in depth from zero at the brook (assuming the brook is hydraulically connected to groundwater) to 5 to 9 feet below ground surface (ft bgs) in monitoring wells at the Site on January 23, 2015, when measured by NGI (NGI 2015 Report, Table 1). Depth to water can be expected to vary with season and weather. Based on reported well yields for the area (0.75 to 100 gallons per minute), the fractured bedrock appears to have the capacity to transport groundwater in most locations in and near the Site.

6.2 Groundwater Contours and Flow

Water level measurements taken by NGI in overburden monitoring wells and piezometers in 2015 allow contouring the groundwater potentiometric surface (water table), although the spacing of the data allows varying interpretations. (See Attachment C for more detailed technical notes and considerations regarding water level measurements and contouring.) Nobis has assumed that the potentiometric surface follows topographic slope in areas between and beyond direct water level measurements. Uncertainty could be reduced by installing additional monitoring wells or piezometers and conducting a new round of water level measurements. In the vicinity of proposed SDA 1, the predicted groundwater flow direction is eastward, with components of flow to the south and southwest also possible, based on topography. In the vicinity of proposed SDA 3, the predicted groundwater flow direction is east-northeastward and northeastward, with components of flow to the east and south also possible, based on topography (Figure 1).

There are no monitoring wells in the vicinity of proposed SDA 2 and therefore no water level measurements in this area. Topographic slopes are small in this part of the Site, based on widely spaced topographic contours, and Nobis assumed (Phase 2 report) that groundwater potentiometric surface contours in the overburden roughly parallel topographic contours. With no new water level data in 2016, Nobis has used the same contours and groundwater flow interpretations (Figure 1), and these indicate eastward flow from SDA 2.

Metamorphic bedrock beneath the site is crystalline and can be expected to have near-zero porosity and permeability (hydraulic conductivity) in the rock matrix. Groundwater flow can only occur in open fractures in the bedrock. Predicting the exact groundwater flow paths in fractured rock and the flow of water to wells completed in fractured bedrock is difficult and highly site specific. It is generally safe to assume that water flowing through bedrock or to a well completed in bedrock is ultimately recharged from overburden above the bedrock, except where bedrock is exposed at the surface.

The degree of hydraulic connection between overburden groundwater and bedrock groundwater at the Site has not been characterized. Such characterization is key to determining the degree of impact that may occur to bedrock wells, such as those proposed for the PWS, due to the proposed septic systems. If dense, low permeability glacial till deposits are present on top of the bedrock in some locations, these deposits may inhibit flow between the overburden and the bedrock. This situation is illustrated by the conceptual cross section in Figure 4a. Conversely, if permeable sandy deposits extend to the top of bedrock, impacted groundwater from the overburden may infiltrate into bedrock fractures and pose a threat to bedrock wells, as illustrated in Figure 4b. Proposed wastewater discharge will be to the overburden; all new and proposed wells obtain their water from the bedrock.

Logs for eight monitoring wells drilled at 5 locations by NGI (NGI 2015 Report, Appendix A) indicate "refusal" at the bottom of each boring. "Competent bedrock" is noted at the bottom of MW-4-15 and MW-5-15, but the geologic reason for refusal at the other sites is less clear.

Generally, refusal can be caused by bedrock, boulders or cobbles, or dense glacial till (hardpan) and may be subject to the drilling method. A dense glacial till, where present, can provide a hydraulic barrier between overburden and bedrock (as in Figure 4a). Logs for MW-4-15 and MW-5-15, which appear to have reached bedrock, do not clearly indicate whether the bedrock is mantled with low-permeability material.

If dense, glacial till or other low-permeability deposits overlie the bedrock, groundwater flowing through bedrock fractures beneath the Site may be isolated from overburden groundwater (and septic discharges) at the Site. In this case recharge to the bedrock groundwater must occur offsite, or very slowly. If permeable overburden overlies fractured bedrock directly, bedrock beneath the Site may receive recharge directly from overlying soils, and discharge from septic systems may enter the bedrock fractures. Similarly, in areas where groundwater discharges from bedrock, the bedrock groundwater may flow upward into overburden deposits, wetlands, or streams, depending on whether the bedrock is mantled by an impermeable layer or not. (See Figures 4a and 4b.) Finally, the pumping of wells completed in fractured bedrock changes the flow patterns in the rock and possibly in the overburden above.

As stated above, specific flow paths in bedrock are difficult to characterize, but information regarding the bedrock fracture system can indicate which transport directions are most likely. Measurement of bedrock outcrop fractures during Phase 2 in an outcrop located just east of the brook where the PWS wells are proposed (Figure 3) showed that the fractures most commonly strike northeast/southwest (NE/SW) and dip steeply. These fractures generally occur along metamorphic foliations (layers) in the rock. In some of the rocks, northwest/southeast (NW/SE) striking fractures are also present; these parallel several photolineaments in the area, also shown on Figure 3 and described in Nobis' Phase 2 report. NE/SW is the most likely direction for groundwater flow in the bedrock, because it is the most commonly observed fracture direction in on-Site outcrops and is also the primary direction for metamorphic foliation, with flow in the NW/SE direction also expected. Examination of two off-site outcrops show similar fracture orientations, so the same predominant flow directions can be expected in the vicinity. Note that this evidence does not guarantee flow along any particular path in any particular location or direction, nor does it guarantee that groundwater cannot flow in other directions.

Hypothetically, if impacted groundwater were to enter fractured bedrock directly beneath any of the proposed SDAs, the groundwater might then be expected to flow to the NE, SW, NW, or SE from the SDA. This flow might be enhanced if a pumping bedrock well is located in these directions relative to an SDA. As described above, if the leachfield are underlain by low-permeability material, there may be no infiltration of impacted groundwater into bedrock directly beneath the SDA. Finally, while the potentiometric surface for overburden groundwater probably mirrors surface topography, flow in bedrock fractures can cross surficial drainage divides. This means that wells that are apparently upgradient of the proposed SDAs cannot be assumed to be unimpacted, especially if they are in close proximity.

The on-Site outcrop east of the brook is aligned in the primary fracture and metamorphic foliation direction (NE/SW), as is the segment of the brook in that immediate area. This is the location in which the PWS wells are proposed. It is likely that the proposed wells will draw their water from fractures aligned in the NE/SW direction. If this is the case, pumping interference may occur between wells aligned with each other in this direction. For example, proposed PWS Wells 1, 2, and 3 might interfere with each other, as might Wells 4 and 5. Signs of such interference might be noted during well drilling, airlift tests, or pumping tests. It is also possible that water might be drawn to the wells from the NW or SE. Finally, although the proposed pumping rates are low, the pumping of these wells, individually or collectively, might affect water levels in neighboring wells, especially wells located to the NE, SW, NW, or SE of the proposed PWS wells. Water level monitoring during a pumping test of the new wells could assess this possibility.

6.3 Notes on Wetland Hydraulics

Whether or not pumping any of the proposed PWS wells will impact the wetland associated with the brook or flow in the brook depends on whether or not the brook and wetland are hydraulically connected to groundwater. Some wetlands and surface water bodies are "perched" above groundwater and are hydraulically disconnected from groundwater in the overburden and/or bedrock beneath. In this case pumping bedrock wells in the area would not be expected to impact the wetlands or stream flow. This perching could occur if low-permeability peat or organic muck underlies the brook and wetland and provides separation from groundwater beneath.

Based on the presence of bedrock outcrops only a few tens of feet east of the brook, it is likely that the overburden is fairly thin in this area and that the brook and wetland receive groundwater discharge. However, Nobis is unaware of borings in the wetland or other evidence that would indicate whether this is the case or whether the wetlands are perched and disconnected from overburden and bedrock groundwater beneath.

7.0 MASS BALANCE NITRATE LOADING ANALYSES

7.1 Method and Assumptions:

The Town requested that Nobis calculate nitrate loading and mass balance according to the method presented in "Guidelines for Title 5 Aggregation of Flows and Nitrogen Loading, 310 CMR 15.216", revised 2/22/16 (Guidelines) as closely as is feasible. The Town and Nobis recognize that in some cases this means using generalized inputs or assumptions instead of inputs or assumptions that are site-specific. The Town has further requested that Nobis conduct calculations for Areas of Impact (AOIs), to be delineated according to the Guidelines and that these AOIs should extend down gradient to property lines or "sensitive receptors", such as drinking water wells.

The Guidelines prescribe assumptions and inputs, and these are presented and discussed in Attachment D.

7.2 Area of Impact Selection and Delineation:

Nobis conducted nitrate mass balance calculations over separate Areas of Impact (AOIs) for proposed SDAs 1, 2, and 3. The Town requested that Nobis select sensitive receptors, property lines, or potential hydrogeologic discharge points that are down-gradient and closest to each of these SDAs and delineate the AOIs for these receptors according to the methods presented in the Guidelines (p. 11 – 12) and summarized in Attachment D.

The Guidelines, Step 1 of the mass balance procedure (p. 11), call for delineating the AOI by flow net analysis, in the downgradient direction. The upgradient edge of the AOI is defined by the upgradient edge of the SAS (soil adsorption system, in this case the proposed Septic Disposal Areas – (see Figure 3)). The Guidelines state that the "lateral extent of the AOI must be established by the groundwater divides developed beneath the SAS at design flow." An exception is called for "where groundwater mounding is not significant." In this case, "the lateral extent of the AOI will be the lateral extent of the leach bed or disposal area." This means that the AOI will be generally rectangular in cases where mounding is not significant.

The Guidelines' instructions for Step 1 allow hydrogeologic interpretation and discretion in defining the downgradient and side gradient boundaries of the AOIs. Because the downgradient boundary is determined by flow net (a map of groundwater flow directions based on groundwater contours), a groundwater contour map is critical, not only for determining the orientation of the AOI, but also for determining which sensitive receptor (drinking water well) is the closest receptor in the down-gradient direction. Discretion is also needed to determine whether mounding is "significant." If the mounding is determined to be "significant", then the groundwater contour map is again critical for defining the side boundaries of the AOI.

7.2.1 AOI for Septic Disposal Area 1

In Section 5.2, Nobis concluded that the predicted mound height of 0.81 feet is not enough to alter the groundwater contouring around proposed SDA 1, although radial flow is possible in the immediate vicinity. Therefore, Nobis believes that in this case, mounding is not "significant", and the AOI associated with Septic Area 1 should have a width equal to the lateral extent of the disposal area. The main component of groundwater flow in this area is eastward, and the AOI extends to the property line, which is encountered prior to a sensitive receptor (well) in the eastward direction.

Therefore, Nobis has delineated a generally rectangular AOI (lateral boundaries slightly curved to be perpendicular to groundwater contours in the area), extending from SDA 1 to the property line, as shown on Figures 3 and D1. The upgradient boundary of the AOI is the upgradient boundary(ies) of the proposed SDA (in this case the northwestern and southwestern boundaries); the side gradient boundaries are defined by the lateral extent of the SDA (in this case, its diagonal); and the downgradient boundary is the property line.

For shallow, unconfined groundwater, the potentiometric surface (water table) usually conforms approximately to topography. Based on topography near SDA 1, components of groundwater flow to the south and southwest are also possible (flow arrows with question marks on Figures 1 and 3). Because sensitive receptors (wells at 68 Garnet Rock Drive and at 200 Long Ridge Road) are present in these directions, Nobis delineated two alternate AOIs in these directions (Figure D1). Because of the lack of water level measurements in these locations, groundwater contouring and flow directions are uncertain. Placement of additional monitoring well(s) to the south and/or southwest of SDA 1, with a new synoptic round of water level measurements would determine whether groundwater flow in these directions should be expected.

7.2.2 AOI for Septic Disposal Area 2

Although the predicted mound height for SDA 2 (1.79 ft; see Section 5.2) is potentially significant enough to alter groundwater contouring, Nobis has not done so for the following reasons:

- Existing groundwater contours in this area are widely spaced, reflective of the gentle topography in the vicinity of SDA 2 (Figure 1).
- The lack of water level measurements in the vicinity of SDA 2 lends uncertainty to the existing contouring.

Because the mounding appears to be "significant" according to the Guidelines, the AOI should be based on groundwater divides and not be simply a rectangle whose width is equal to the lateral extent of the Septic Disposal Area. However, there is not enough data to either alter contouring or delineate groundwater divides. Therefore, Nobis has used an intermediate approach that shows a slightly fan-shaped AOI (Figure 3), with lateral boundaries perpendicular to the groundwater contours. The fan-shaped AOI produces a lower nitrate concentration result than a strictly rectangular AOI, because more area is available for recharge of infiltrated precipitation.

The AOI associated with SDA 2 extends eastward from the up-gradient (western) edge of the SDA to the nearest sensitive receptor, proposed PWS Well 1 (Figure 3). Nobis also performed calculations for smaller portions of the AOI, as follows:

- AOI 2A (Figure D2) extends to near the up-gradient edge of the existing septic system for the existing house, to determine the amount of loading and dilution that might occur prior to adding the nitrate load from this septic system.
- AOI 2B (Figure D2) terminates at the edge of the composite Zone I (inner Wellhead Protection Area) for the proposed PWS wells.
- AOI 2C (Figure D2) is the entire AOI described above.

Nobis notes that although the existing well for the existing home is outside the delineated AOI for SDA 2, there is sufficient uncertainty in groundwater contouring and flow directions in this area so that the well could, in reality, be down-gradient of SDA 2. While this well is to be used for irrigation and not for drinking, steps should be taken to assure that future occupants never use this well as a drinking water source unless it is demonstrated not to be impacted by SDA 2.

7.2.3 AOI for Septic Disposal Area 3

Although the predicted mound height for SDA 3 (1.76 ft; see Section 5.2) is less than for SDA 2, it is potentially significant enough to alter the groundwater contouring in this area, and the contouring has been done with more confidence than for SDA 2. The increased confidence is due to greater topographic slope in this area and the presence of several monitoring wells from which NGI obtained water level measurements in 2015. See Figure 3 for interpreted contours that take mounding into account (red contours). However, some uncertainty remains, and radial flow from SDA 3 is likely to be local, with northeasterly flow still dominant. Therefore, Nobis' interpreted AOI is significantly broader than the width of the SDA, but does not extend all the way to an interpreted groundwater divide (described in the 2015 Addendum to Nobis Phase 2 Report) shown on Figure 3.

In the northeasterly direction, a brook and wetland is encountered prior to any "sensitive receptor" wells. In the absence of other information, the brook and wetland are the likely discharge points for overburden groundwater flowing from SDA 3. Therefore, the AOI is delineated down gradient to this location. The AOI is subdivided, so that AOI 3A extends only to the property line, while AOI 3B is the entire AOI described above (Figure D3).

7.3 Results:

7.3.1 AOI for Septic Disposal Area 1

The AOI for Septic Disposal Area 1 (AOI-1A on Figure D1 in Attachment D) has a total area of 15,360 square feet, of which 4,580 square feet is impervious (proposed home #2, part of home #3, and road and driveway). The impervious area is discounted from the recharge total according to the Guidelines. As described above, fertilizer is assumed to be applied to future lawns (estimated by Nobis for the new proposed housing layout, based on "loam and seed areas" shown on Landscaping Figure 1 of 2 in Brem 197 03-31-2015). These areas account for 4,143 square feet and were used to calculate the nitrate load due to fertilizer, as described above. When the inputs are applied to the formula in Step 4 of the Guidelines, the resulting nitrate load for a year is 51,982,328 mg; the total volume of water is 3,193,559 L; the resulting predicted nitrate concentration is 16.3 mg/L at the property line (Scenario 1 in Table 4). This calculation used the Applicant's design discharge based on 110 gpd per bedroom. If the Town's rate of 165 gpd per bedroom is used, the predicted nitrate concentration is 17.1 mg/L at the property line (Scenario 2 on Table 4). The larger predicted nitrate concentration for Scenario 2 is due to the larger simulated volume of wastewater that contains concentrated nitrate.

If groundwater flows to the south and/or southwest from SDA 1, alternate AOIs may be pertinent. Nobis delineated two such AOIs as hypothetical cases. These extend down-gradient to wells at 68 Garnet Rock Drive and 200 Long Ridge Road. Nobis points out that the results represent relative average concentrations in overburden (not bedrock) groundwater and not predicted concentrations at the wells. In the calculations, Nobis assumed that no fertilizer is applied outside of the Site and that the existing septic systems for the homes are outside of the AOIs. (In other words, only effluent from SDA 1 is considered as a source of nitrogen.) Results for AOI Alt1 (extending south toward 68 Garnet Rock Lane) indicate a nitrate concentration of 14.3 mg/L using the Applicant's design septic rate. Similarly, the result for AOI-Alt 2 (to the southwest, toward 200 Long Ridge Road, is 13.7 mg/L. these results should be considered relative, and all the predicted concentrations for AOI 1 may be higher than actual results if radial flow exists and only a portion of the effluent from SDA 1 flows in any given direction (east, south, or southwest).

The existing well that serves the home at 90 Long Ridge Road is also downgradient of SDA 1, but farther away than the down-gradient edge of the SDA at the property line. Nobis did not delineate an AOI extending to this well or perform a nitrate mass balance calculation. Therefore, at present there is not enough information to conclude that a result at 90 Long Ridge Road would be less than 10 mg/L or 5 mg/L for nitrate.

<u>It must be remembered that all calculations presented here are for the overburden and assume that all wastewater that is discharged fully mixes with groundwater in the AOI. The results for AOI-1A, AOI Alt 1, and AOI Alt 2 are for the overburden and are not predictions of nitrate concentrations in bedrock in a well or at the property line.</u>

7.3.2 AOI for Septic Disposal Area 2

The AOI for proposed SDA 2 (AOI-2C) has an area of 42,146 square feet, of which 8,497 square feet is impervious (existing home, part of proposed home 5, and driveways and road). The impervious area is discounted from the recharge total according to the Guidelines. As described above, fertilizer is assumed to be applied to future lawns (estimated by Nobis for the new layout from "loam and seed areas" shown on Landscaping Figure 1 of 2 in Brem 197); these areas account for a total of 6,627 square feet and were used to calculate the nitrate load due to fertilizer, as described above. When the inputs are applied to the formula in Step 4 of the Guidelines, the resulting predicted nitrate concentration is 15.4 mg/L (Scenario 11 in Table 4).

If the AOI for SDA 2 were reduced as described in Section 7.2.2 so that the down-gradient edge is at the border of Zone I instead of at proposed Well 1 itself, there would be less area for recharge to provide dilution, so that the corresponding result for AOI 2B would be 17.9 mg/L (Scenario 9 in Table 4). If the AOI were reduced farther, so that it terminates up-gradient of the septic system for the existing home (AOI 2A in Figure D2), the predicted nitrate value would be less (17.0 mg/L in Scenario 7 in Table 4). Although there is less area for recharge in AOI 2A than in AOI 2B, there is a lesser nitrate load because the existing, untreated septage from the existing home is not included, whereas Scenario 9 includes discharge from the existing septic system, which must be simulated with a nitrate concentration of 35 mg/L because it is a conventional system.

As described in Sections 4.0, 5.1, and 7.2.2, there is considerable uncertainty associated with all AOI 2 calculations and interpretations due to the lack of data in this vicinity. Nobis recommends that one or more new monitoring wells or piezometers should be installed to determine geologic and groundwater conditions in this area.

It must be remembered that all calculations presented here are for the overburden and assume that all wastewater that is discharged fully mixes with groundwater in the AOI. The results for AOI-2 at proposed well PWS Well 1 are for the overburden and are not predictions of nitrate concentrations in bedrock in a well to be drilled at the location.

7.3.3 AOI for Septic Disposal Area 3

The AOI for proposed SDA 3 (AOI-3B) has an area of 122,688 square feet, of which 23,159 square feet is impervious (proposed homes 10 – 14 and 18, driveways, and road). The impervious area is discounted from the recharge total according to the Guidelines. As described above, fertilizer is assumed to be applied to future lawns (estimated by Nobis for the new layout from "loam and seed areas" shown on Landscaping Figure 1 of 2 in Brem 197); these areas account for a total of 35,526 square feet and were used to calculate the nitrate load due to fertilizer, as described above. When the inputs are applied to the formula in Step 4 of the Guidelines, the resulting predicted nitrate concentration is 7.5 mg/L (Scenario 15 in Table 4).

Note that this estimate is for an AOI that terminates at a brook and wetland that represent the possible discharge point for shallow groundwater that flows from the vicinity of SDA 3. The brook and wetland might be considered a hydraulic or ecological receptor, but not a "sensitive receptor" (drinking water well) as defined by MassDEP. The well at 55 Suffolk Lane Extension is farther to the northeast but topographically uphill from the brook and wetland and not a likely destination for shallow, overburden groundwater that flows from the vicinity of SDA 3.

If the AOI for SDA 3 were reduced as described in Section 7.2.3 so that the down-gradient edge is at the property line instead of at the brook and wetland, there would be less area for recharge to provide dilution, so that the corresponding result for AOI 3A (Figure D3) would be 11.5 mg/L at the property line (Scenario 13 in Table 4). Note that this is an average for the AOI 3A sub-area and that the property line is oblique to the flow direction. In some locations, the property line is only a few feet away from the edge of SDA 3, so the nitrate concentration may be much higher at some points along the property line and much lower at other points.

It must be remembered that all calculations presented here are for the overburden and assume that all wastewater that is discharged fully mixes with groundwater in the AOI. The results for AOI-3 at the brook and wetland or at the property line are for the overburden and are not predictions of nitrate concentrations in bedrock in a hypothetical well at the locations.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The Applicant has proposed a 40B development consisting of 19 new homes and one existing home, to be served by a PWS that includes seven new bedrock wells and a shared septic system with three SDAs and an existing leachfield, on a 9.84-acre lot at 100 Long Ridge Road in Carlisle, Massachusetts (Site). The 2016 proposal by the Applicant differs from a proposal submitted in 2015 in that the 2015 proposal called for 9 private wells instead of a PWS, and the 2015 proposal called for two of the SDAs to be located adjacent to each other in the northwestern part of the Site. The 2016 proposal calls for three leachfields to be located separately, along the western Site boundary. Concerns have been raised regarding the 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 new wells and the existing nearby wells. Also, potential interference effects between the proposed new wells are a concern.

The Site is underlain by sandy glacial till (0 to 24 feet thick), which is underlain by fractured and variably foliated metamorphic bedrock. Predominant bedrock fracture orientations are northeast and northwest, with steep dips. Because there is essentially no porosity or permeability in the rock matrix, these fractures represent the primary avenues for groundwater flow within the bedrock. In the overburden, groundwater occurs in the pore spaces within the unconsolidated deposits and flows from areas of higher head to areas of lower head. Based on available information, overburden groundwater is expected to flow eastward from proposed SDA 1, with possible flow also to the south and southwest. Overburden groundwater is expected to flow eastward from proposed SDA 2, but there are no water level data available in this area, so interpretations are uncertain. Overburden groundwater flow is expected toward the northeast from proposed SDA 3, with flow to the east and south also possible.

The degree of hydraulic connection between overburden groundwater and bedrock groundwater at the Site has not been characterized. If dense, low permeability glacial till deposits are present on top of the bedrock in some locations, these deposits may inhibit flow between the overburden and the bedrock. If a low-permeability layer is absent, impacted overburden groundwater is more likely to reach a well drilled in bedrock. Proposed wastewater discharge will be to the overburden; all new and proposed wells obtain their water from the bedrock.

The proposed PWS presents a qualitative improvement for some of the concerns addressed by Nobis, as compared to the private well plan proposed in 2015. The improvements are due to the greater distance between the proposed SDAs and the proposed wells, although the wells are still down-gradient from the proposed SDAs. Also, separating proposed SDAs 2 and 3 will result in a lower groundwater mound in each location than had been estimated in 2015 when these two

SDAs were adjacent. However, proposed SDA 2, in its new location, is directly upgradient of the existing septic system for the existing home, and both of these are directly upgradient of the southern portion of the wellfield proposed to serve the PWS.

Permitting decisions regarding the PWS will be made primarily by MassDEP, but several questions relevant to Nobis' assessments are associated with the PWS. These questions include the maximum daily demand for the system and the yields and pumping rates of the individual wells; the final locations of the wells and their Zone Is; whether the wells will be under the direct influence of surface water and whether the brook and wetland in the eastern part of the Site will be impacted by well drilling or pumping; and the likelihood that the well Zone Is cannot be "counted" as part of the 440 gpd per acre equivalency standard.

The NGI 2016 report includes results of new nitrate dispersion analyses, provides a summary of the proposed PWS, comments on mass balance/nitrate loading analyses, and discusses other aspects of the revised 40B proposal, but does not provide any new on-site data. NGI's dispersion results assume overburden groundwater flow patterns similar to those interpreted by Nobis and provide nitrate concentration results ranging from less than 1 mg/L to about 3 mg/L at potential well receptors. Higher results, up to 17 mg/L were obtained for flow lines that terminate at property boundaries. The results apply to overburden, not bedrock, groundwater. Existing background concentrations for nitrate in groundwater probably range from 0.5 mg/L to 1.0 or 1.5 mg/L.

Discharge of wastewater to the Proposed SDAs will create groundwater mounds whose predicted height depends on model assumptions and inputs. After 180 days of discharge and using site-specific hydraulic conductivity, Applicant-designed discharge of 1,980 gpd for each SDA, and other input parameters, maximum mound heights of 0.81 feet through 1.79 feet above the existing water table are predicted for the SDAs. Mound heights differ for other loading rates or assumptions. The prediction for SDA 2 is more uncertain than for SDA 1 and 3 because no water level or other data is available from the immediate vicinity in the new location. When proposed SDA 3 is modeled, the predicted groundwater mound is less than 4 feet below the present ground surface. Also, the mound height predicted for this SDA is high enough to modify the groundwater contouring slightly. This may also be the case near SDA 2, but the results are too uncertain to justify modifying groundwater contours. These groundwater mounds can be expected to increase groundwater gradients and flow velocities and may create radial flow in the immediate vicinities of the Proposed SDAs, but do not significantly alter the groundwater flow directions at the Site scale.

Nitrate mass balance analyses predict overall average nitrate concentrations for overburden groundwater in a given area but do not predict concentrations at a point. As with any modelling, the accuracy of these predicted concentrations depends on the simplifying assumptions inherent to the model and on the accuracy of the input values. With these cautions in mind, the mass balance results indicate that for either the Applicant's or the Town's proposed wastewater design flows, there may not be sufficient dilution to reduce nitrate concentrations below 10 milligrams per liter on the average for Areas of Impact (AOIs) delineated according to MassDEP Guidelines and extending from SDAs to proposed PWS wells, Zone Is, existing private wells, other receptors, or property lines. These results are averages predicted for AOIs, not for point receptors, and are relative values to be compared to each other.

These predictions apply to nitrate concentrations in overburden groundwater, not in bedrock groundwater, nor are they directly comparable to the concentrations predicted by the dispersion analysis approach. However, mass balance calculations and dispersion analyses model complementary physical processes that occur when wastewater discharges from a septic system and impacts flowing groundwater. Mass balance analyses consider certain inputs and outputs and model the physical process of dilution that occurs, within a given area, as septic discharge mixes with water that infiltrates into the ground from precipitation. Dispersion analyses model the processes of diffusion and advection from a point source to a point receptor. Results from these two methods should be considered together but not numerically compared to each other or considered as predictors of nitrate concentration in a bedrock well. The results indicate that some portions of the Site are of more concern than others. These include:

- the area east of SDA 2, including the southern portion of the combined Zone Is for the proposed PWS wells;
- the property lines near SDA 3; and
- the property line east of SDA 1 and possibly south of SDA 1.

Uncertainties in groundwater flow directions near SDA 2 and SDA 1 are especially concerning, because these uncertainties make predictions of impacts, even in overburden groundwater, difficult.

Predictions of potential impacts, due to the proposed septic system, to groundwater in fractured bedrock are even more uncertain. Whether or not impacted groundwater in the overburden will flow directly into underlying bedrock through fractures depends on whether or not a low-permeability layer (e.g. dense glacial till) overlies the bedrock. If impacted groundwater from the overburden flows into underlying bedrock fractures, whether or not such groundwater will impact a bedrock well depends on particular bedrock fractures and connections between fractures. There is generally less dilution in bedrock than in permeable overburden, and transport can be faster, when wells are pumping. Present information suggests that wells located to the northeast, northwest, southeast, or southwest of one of the SDAs are more likely to be impacted than wells located in other directions.

Regardless of the presence or absence of a low-permeability layer on top of bedrock, pumping interference (water levels and well yield) is likely to occur between the proposed PWS wells. Also, interference between the proposed PWS wells and existing residential wells cannot be ruled out, although these are at greater distance.

Nobis offers the following recommendations, some of which are intended to provide information needed to fill data gaps and evaluate key questions for which the present information is insufficient.

1. Nobis recommends that the Town request the Applicant to obtain site specific information in the new location for SDA 2. At least one boring should be drilled in this area, and it should extend deep enough to reach confirmed bedrock. A monitoring well(s) should be installed in the boring(s), whose log(s) should include a geologic description of the formations encountered. Saturated thickness and hydraulic conductivity should be obtained for the well(s).
2. Nobis recommends that the Town request the Applicant to conduct a new round of water level measurements, on the same date, from all existing and new on-site monitoring wells, piezometers, and staff gauges. Nobis and/or the Applicant's consultant should construct overburden groundwater contour maps using the new data.

3. The nature of the overburden/bedrock interface (presence or absence of low-permeability layer on top of bedrock) needs to be characterized in order to assess potential impacts on existing and proposed bedrock wells. Therefore, Nobis recommends that the Applicant drill at least two borings deep enough to confirm the depth to bedrock and to characterize the geologic deposits that overlie bedrock. One of the borings can be the one recommended above, near SDA 2. Another such boring is recommended near the wetland/brook. (Results of such a boring could also be used to indicate whether the wetland is perched or hydraulically connected to overburden groundwater.) Additional boring locations, listed in Nobis' Phase 2 report, would still be beneficial.
4. Additional information on the hydraulic connection (or lack thereof) between overburden and bedrock groundwater could be assessed by placing transducers, programmed to collect water level measurements over a week or more, in the on-Site overburden monitoring wells. The water level data could then be analyzed to see if there is a response to pumping cycles in the existing on-Site well or other nearby pumping wells.
5. Before significant additional time or expense is incurred, Nobis recommends that the Town and/or the Applicant confirm with the MassDEP Regional Office that the proposed PWS Zone Is cannot be "counted" as acreage for the nitrogen equivalency requirement of 440 gpd of wastewater per acre.
6. Nobis recommends that if the Town grants a permit for the presently proposed 40B project, the permit be conditioned, not only on MassDEP approval of the proposed PWS, but also on the Applicant providing the Town with copies of key results and permit submittals. This should include drilling logs for the PWS wells, pumping test results, water quality results, permit applications and reports submitted to MassDEP, and significant correspondence with MassDEP. For example, any significant change of well location, Zone I location, well yield, etc. should be communicated to the Town during the testing and permitting process.
7. After the PWS wells are drilled but before pumping tests are conducted, the Town should have the opportunity to review the proposed pumping test plan. Nobis recommends that a permit condition should state that the Applicant will grant any reasonable request on the Town's part that the Applicant monitor neighboring wells during the pumping test.

9.0 REFERENCES

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We look forward to continuing to work 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

Tables:

Table 1. Input Parameters for Mounding Analysis
Table 2. Mounding Analysis Results, LGH Loading Rates
Table 3. Mounding Analysis Results, Town Loading Rates
Table 4. Mass-Balance Nitrate Loading Analyses Results

Figures:

Figure 1. Overburden Characteristics, Proposed Septic Disposal Areas, and Wells
Figure 2. Bedrock Characteristics, Proposed Septic Disposal Areas, and Wells
Figure 3. Areas of Impact, Proposed Septic Disposal Areas, and Wells
Figure 4A. Conceptual Cross Section – Scenario A
Figure 4B. Conceptual Cross Section – Scenario B

Attachments:

Attachment A. Applicant's Plan P – Public Water Supply
Attachment B. Bedroom Counts and Proposed Septic System Loading Rates
Attachment C. Notes on Hydrogeology, Groundwater Flow, and Mounding Analysis
Attachment D. Notes on Nitrate Mass Balance Calculations and AOI Maps