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January 24, 2022

Joe Tamposi, Jake Tamposi
Brookline Opportunies LLC
32 Pine Hill Rd, Unit A
Nashua, NH 03063

Dear Joe and Jake:

I am attaching our report on the water supply for the workforce housing project you are planning in Brookline. Based on the information that has been developed at this point, the report assesses the likelihood that Well TW-1N will be capable of supporting your planned development, and it also assesses the likelihood of adverse impacts on owners of offsite wells. Please let me know if you have any questions.

Sincerely,

Fred E. Bickford
Hydrogeologist

Feasibility of Groundwater Source
Workforce Housing Project
Brookline, New Hampshire

January 24, 2022

Introduction

Brookline Opportunities, LLC (BOL), is developing a workforce housing project in Brookline, New Hampshire. The project is to consist of a mix of two-bedroom and three-bedroom units in multi-unit structures constructed on Brookline Lot D-50, and plans call for the project to be served by a community water supply. The residential units will have a total of 192 bedrooms. The proposed water source is a bedrock well located in the northern part of the development property. Figure 1 shows the property outline and the location of the well. It should be noted that the registration of the property outline to the topographic map backdrop may be imperfect, although it is believed to be reasonably accurate. The blue property outline is repeated in later maps.

HydroSource Associates (HSA) was retained by BOL to help find a site for a well productive enough to meet water system demand. HSA has been working in collaboration with Fieldstone Land Consultants on this project. After the well was drilled, BOL asked HSA to provide its opinion on the ability of the bedrock aquifer to meet the water needs of the residential development, and to assess potential impacts on surrounding water users. The purpose of this document is to report the results of HSA's assessments.

We begin by estimating the water demand of the residential development. We then review the hydrogeologic setting of the development property. This review includes bedrock geology, lineaments, surficial geology, and groundwater recharge potential. This is followed by consideration of information on existing wells derived from a wells database maintained by the New Hampshire Department of Environmental Services (NHDES). Finally, we assess the anticipated impact on neighboring water users.

Estimated Water Demand

Regulations administered by NHDES (specifically, PART Env-Dw 405, Design Standards for Small Community Water Systems) include guidelines for determining water demand of residential developments. For housing developments like this one, the rules call for design flow of 150 gallons per day (gpd) for each bedroom. Assuming two bedrooms for each of the 80 units, we have 192 bedrooms, and a project design flow of 28,800 gallons per day (gpd), or about 20 gallons per minute (gpm). Source capacity (that is, the amount of water that the water source must be capable of providing on a sustained basis) is figured at twice design flow. Therefore, testing of the proposed system's supply wells that is required to obtain NHDES approval of the source must demonstrate that they are capable of producing water at a rate of 57,600 gpd, or about 40 gpm. However, actual average daily demand can be expected to be closer to 20 gpm (design flow) than 40 gpm (source capacity).

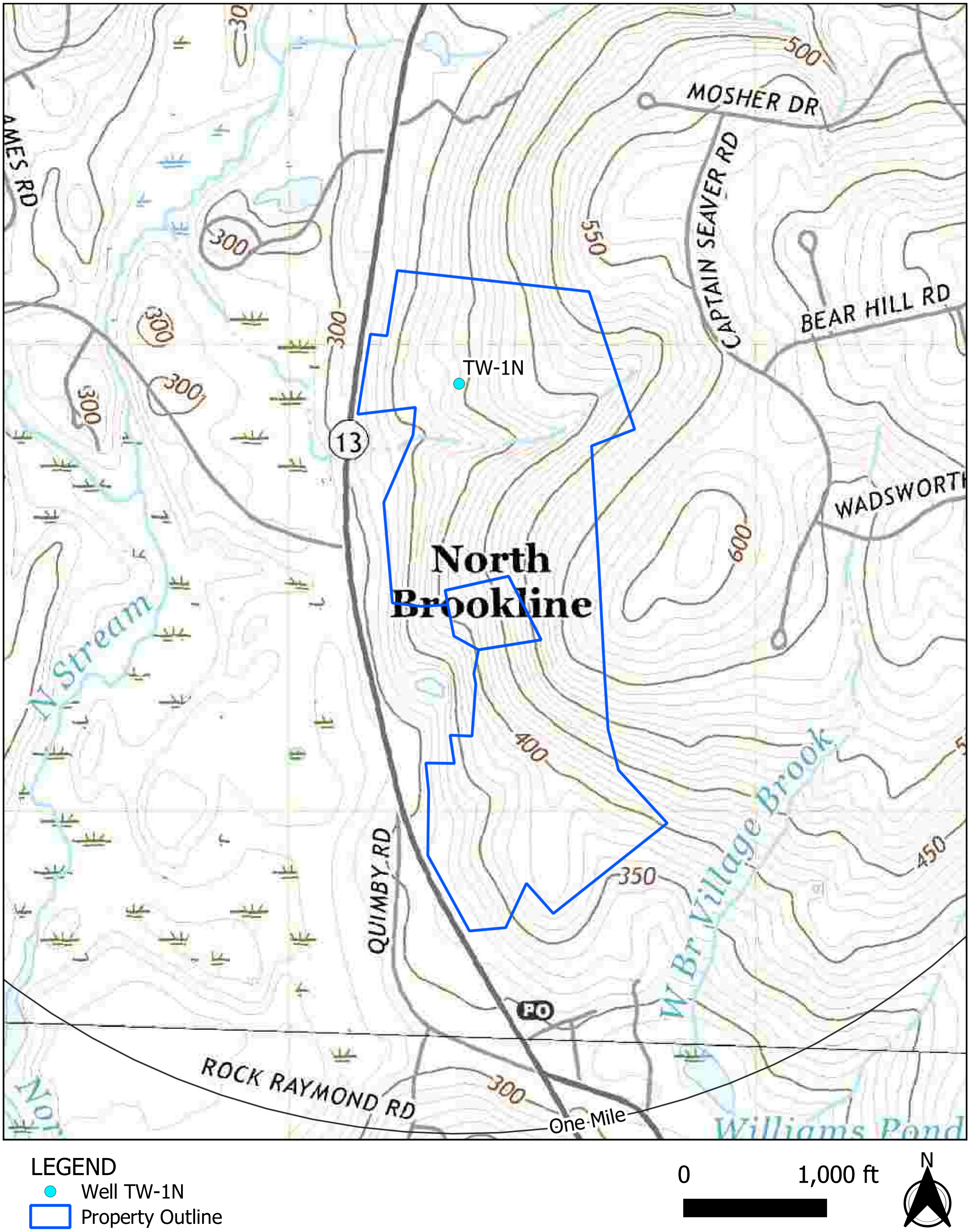


Figure 1 - Development Property

Because wastewater from the development will be handled using on-site septic systems, the majority of the water pumped from the wells will be released back into the ground from septic system leach fields. Some fraction of this treated wastewater can be expected to replenish the bedrock aquifer, so that the development's net extraction rate should actually be considerably less than 20 gpm. This is considered in more detail below.

The new community water system is expected to be supplied by two wells, one considered the primary well, and the second a backup water source to provide source redundancy. As of the date of this report, one well has been constructed, and this well provides an initial indication of the relatively substantial productivity of the bedrock aquifer at the well site. The well, named Well TW-1N, is 400 feet deep and has an airlift yield of 150 gpm from a fracture zone at 389 feet.

The term "airlift yield" refers to the process of using the drill rig to inject compressed air into the well, and then measuring the flow rate of the ejected stream of water. The airlift yield gives only a general indication of the well's potential safe yield, which is the maximum sustainable withdrawal rate as determined with the help of a long-term constant rate pumping test. Nonetheless, the high airlift yield is a strong indication that constant rate testing will show the well to be capable of meeting the minimum sustained flow of 40 gpm required under NHDES regulations for the water source.

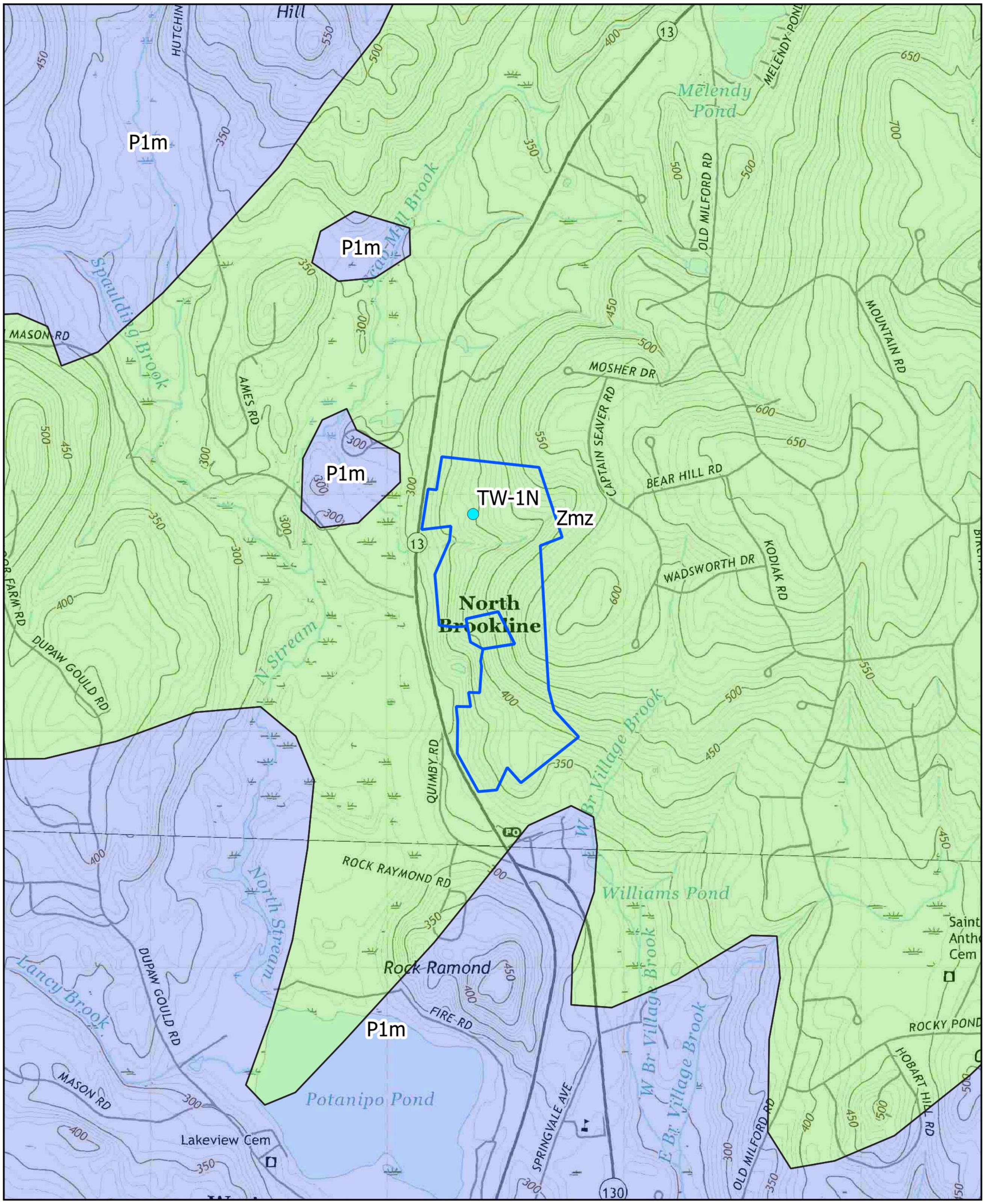
Bedrock Geology

Figure 2 is a bedrock geologic map. The source of the mapped geology is the Bedrock Geologic Map of New Hampshire (Lyons et al., 1997). This area is approximately on the axis of the Massabesic Anticlinorium, a northeast-trending anticlinal fold that runs along the west edge of the Merrimack Trough.

The map shows the property as being entirely underlain by metamorphic rocks of the Massabesic Gneiss. The gneiss consists of quartzo-feldspathic gneiss and biotite schist, granofels, and calc-silicate rocks, which are in places intruded by and grade into a pink gneissic granite. The age of the Massabesic is Late Proterozoic, slightly more than 600 million years old based on isotopic age dating.

The precursor to the gneiss was a sequence of stratified ocean-floor sediments that, following deposition, was folded and metamorphosed during one of the series of orogenic events that produced the Appalachian Mountains. The rock may retain some degree of original sedimentary layering, but it has been so completely recrystallized during high-pressure, high-temperature metamorphism that original sedimentary features (things like bedding planes, cross-bedding, and soft-sediment slumping features) are no longer recognizable. Compositional layering is not strongly developed in most outcrops seen at the project site. The published mapping shows no faults on or near the subject property.

The only other rock type shown on the map is gray biotite granite of Permian age (about 280 million years old).



LEGEND

- Well TW-1N
- Property Outline

Rock Types

- P1m - Permian Granite
- Zmz - Proterozoic Massabesic Gneiss

0 2,000 ft

N

Figure 2 - Bedrock Geology

Lineaments

Lineaments are linear or curvilinear features that can be recognized on maps and map-like products. Some lineaments are the surface expression of steeply dipping planar geologic structures, like faults, zones of close-spaced jointing, or other geologic discontinuities. Some of these features may coincide with zones of concentrated fracturing that allow substantial transmission of groundwater, and this makes lineaments of special interest in bedrock well-siting studies.

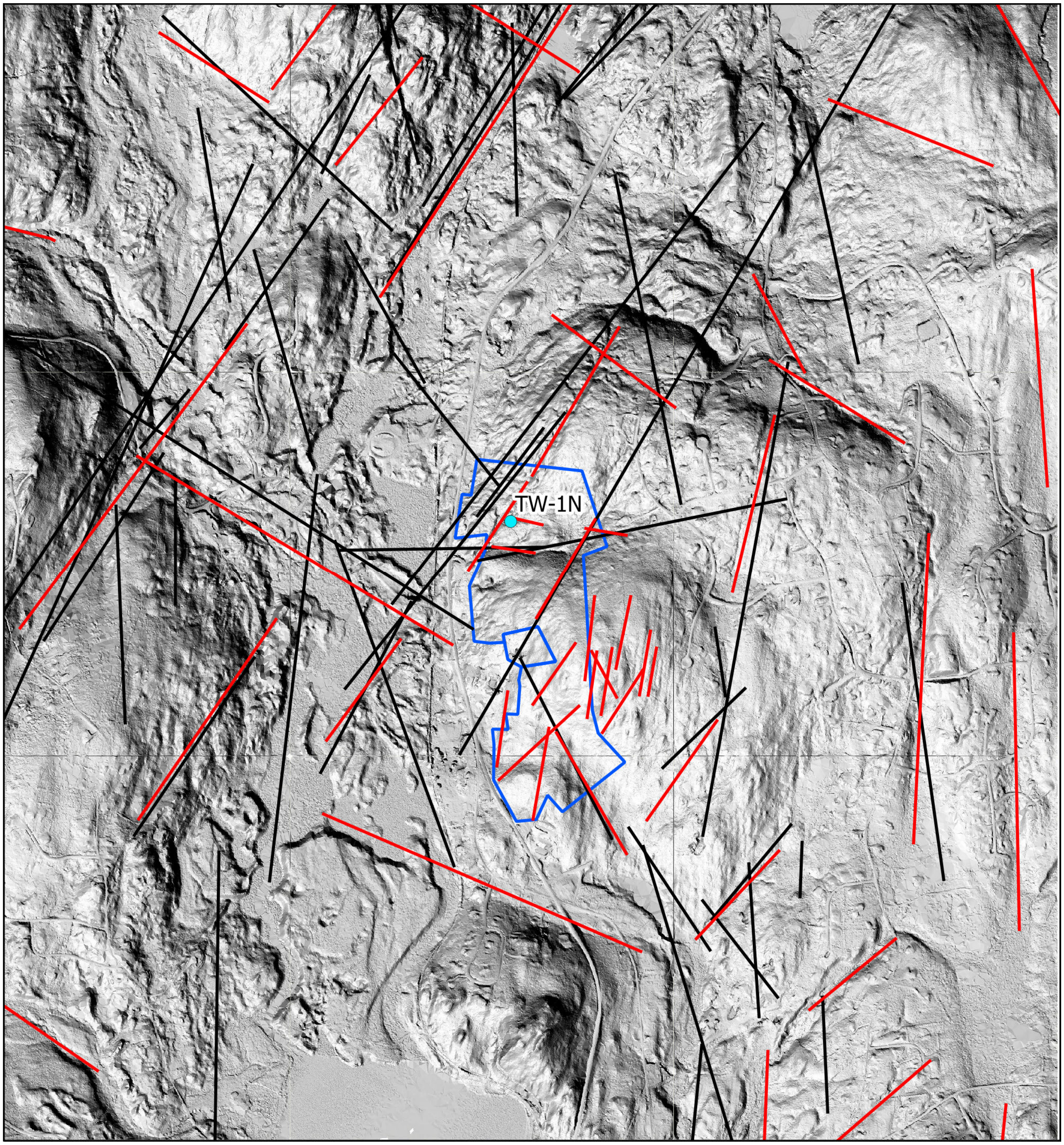
Figure 3 is a lineament map, which uses a hillshaded LiDAR image as a backdrop. To make the backdrop image, the hillshading controls were set to show the topography as it would look if it were illuminated by a light source shining from the southwest, at an angle of 35 degrees above the horizon. The LiDAR image has horizontal resolution of about one-half meter.

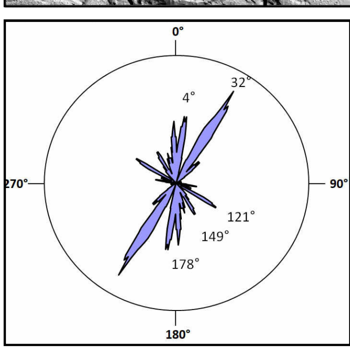
The lineaments shown in red were mapped by HydroSource, and were drawn based on DEM and LiDAR images (including the one used in Figure 3). Multiple hillshaded images were used in the lineament mapping. Images were produced using a range of artificial lighting directions, since some lineaments and lineament patterns are most clearly expressed when the ground topography is viewed using a particular illumination direction.

Lineaments shown in black were obtained from a USGS study meant to help identify bedrock aquifers (Clark et al., 1997). Lineaments mapped in the USGS study were based on aerial photographs and satellite imagery having a wide range of scales.

A rose diagram is provided at the lower left-hand corner of Figure 3. The rose diagram is essentially a circular histogram, showing the frequency distribution of lineament trends. The diagram is based on a total of 113 lineaments (the combined lineaments of HydroSource and the USGS) in the region surrounding the project site, some of them beyond the edges of the map view. The longest "petal" of the rose has a north-northeasterly (NNE) trend (32°), with several smaller petals at other orientations. The NNE trend is parallel to the regional strike of foliation in the metasediments of the Merrimack Trough. This is the dominant direction, the main structural grain of these rocks. Several other shorter petals can be seen, representing subordinate lineament orientations. The petal at 121° represents a common orientation of cross-cutting structural features in the northeastern U. S.

Some of the lineaments with a northwesterly orientation could represent the glacial transport direction. Glacial ice advanced from the northwest or NNW, and produced landforms that are elongate in that direction. Lineaments representing this influence may have limited value in indicating structures corresponding with bedrock aquifers, except to the extent that glacial erosion tends to preferentially attack rock that has been weakened by fracturing, creating overdeepened valleys coincident with the bedrock structure.





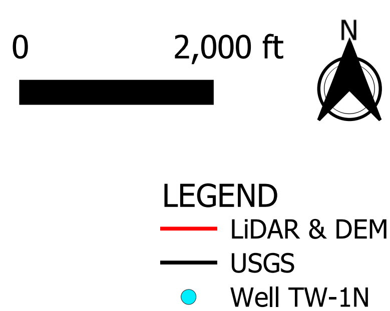


Figure 3 - Lineaments

The Well TW-1N site sits along one of the more prominent members of the NNE-trending lineament set (Figure 3). It is at a point where the NNE lineament comes close to a short lineament with a south-southeasterly trend. Whether the shorter lineament has significance is uncertain. However, the high yield exhibited by Well TW-1N suggests that the water-bearing fractures that feed the well are likely to be in communication with a regional-scale fracture system capable of collecting water over a broad area. This makes it seem more likely that the strong NNE-trending lineament passing by the TW-1N site marks a productive bedrock structure.

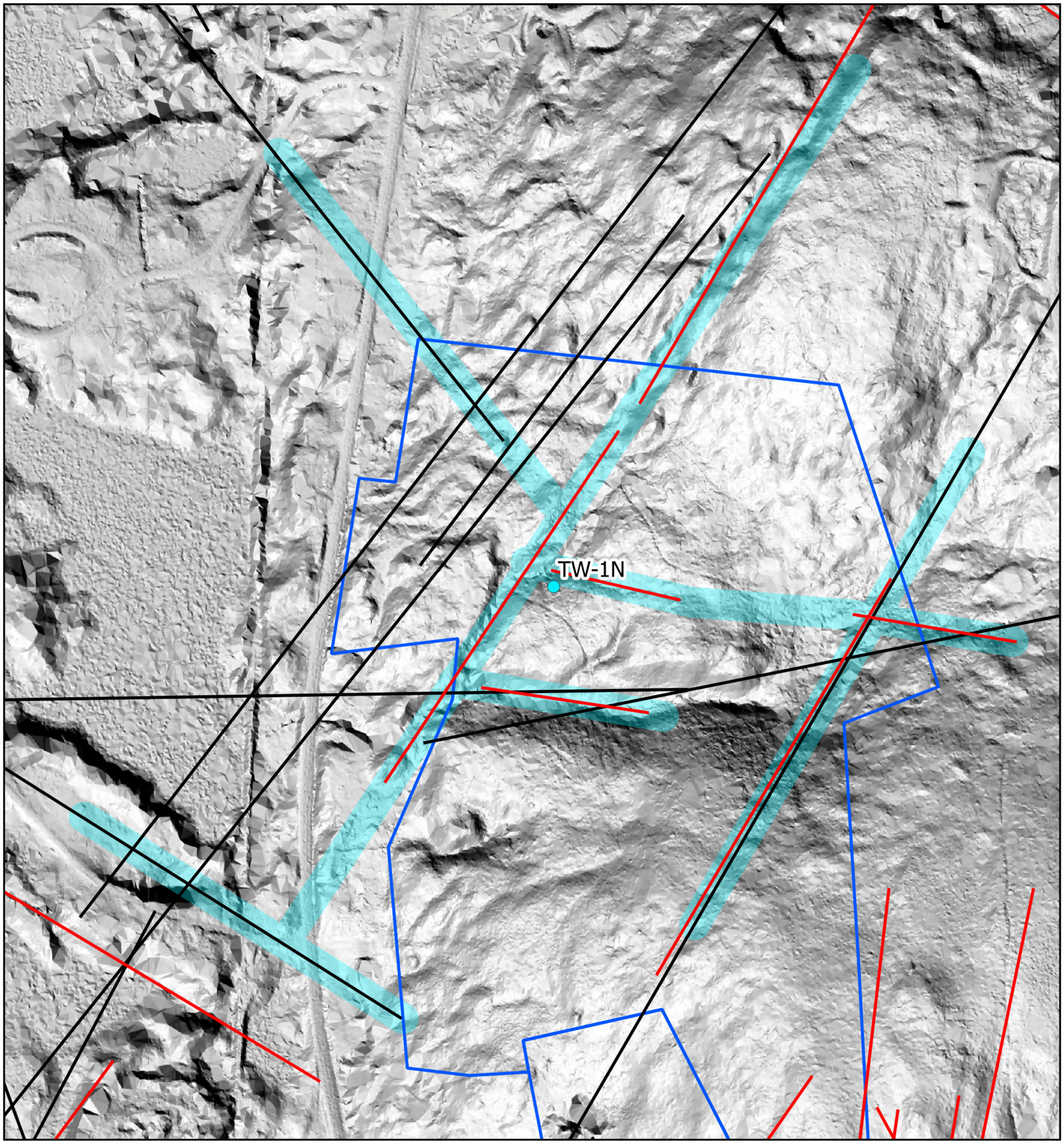
Figure 4 is a zoomed-in version of the same map, in which some of the lineament segments closest to Well TW-N1 have been highlighted with a translucent blue band. We cannot be sure which of the lineaments in the area surrounding Well TW-N1 represent productive bedrock structures. However, if these lineaments mark structures capable of transmitting water, then pumping of Well TW-N1 might be expected to cause water flow toward the well concentrated along the network of interconnected lineament segments marked in blue. If that were true, offsite domestic wells located close to the blue lines might see more impact from pumping TW-N1 than other wells offset from it by a similar distance.

Surficial Geology

Figure 5 is a map showing the extent of stratified-drift aquifers near the project site. Stratified-drift aquifers are aquifers in the unconsolidated sand and gravel deposits that were laid down from meltwater streams during the final stages of the last glaciation. The base map is from a 1987 study by the U. S. Geological Survey (Toppin, 1987).

The map shows areas outlined in shades of blue with varying intensity. The shading represents different categories of transmissivity, with transmissivity being a measure of the ability of an aquifer to transmit groundwater. The map shows that the valley of North Stream, which is north of Potanipo Pond on the west side of Route 13 opposite the subject property, is filled with sand and gravel deposits having considerable transmissivity. These sediments could have the potential to host high-yielding wells.

The project site itself is underlain by glacial till. This material on average has low permeability, and the saturated thickness of these sediments (that is, the thickness below the water table) is low. Thus there was no prospect of developing wells meeting the needs of the project in the unconsolidated sediments of the property. However, the existence of volumes of saturated sand and gravel filling the valleys of North Stream, Scab Mill Brook, and Spaulding Brook means that bedrock wells sited nearby (including locations on the development parcel and on neighboring parcels) may have a significant nearby source of potential recharge, assuming that the wells are fed by fracture systems that penetrate the bedrock surface under the saturated sediments (which is a reasonable assumption). Because the water present in fractured-bedrock aquifers is ultimately derived from water leaking into the bedrock from the surface, this is important.



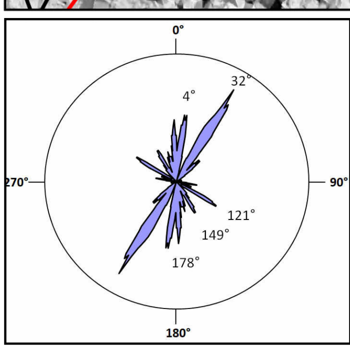
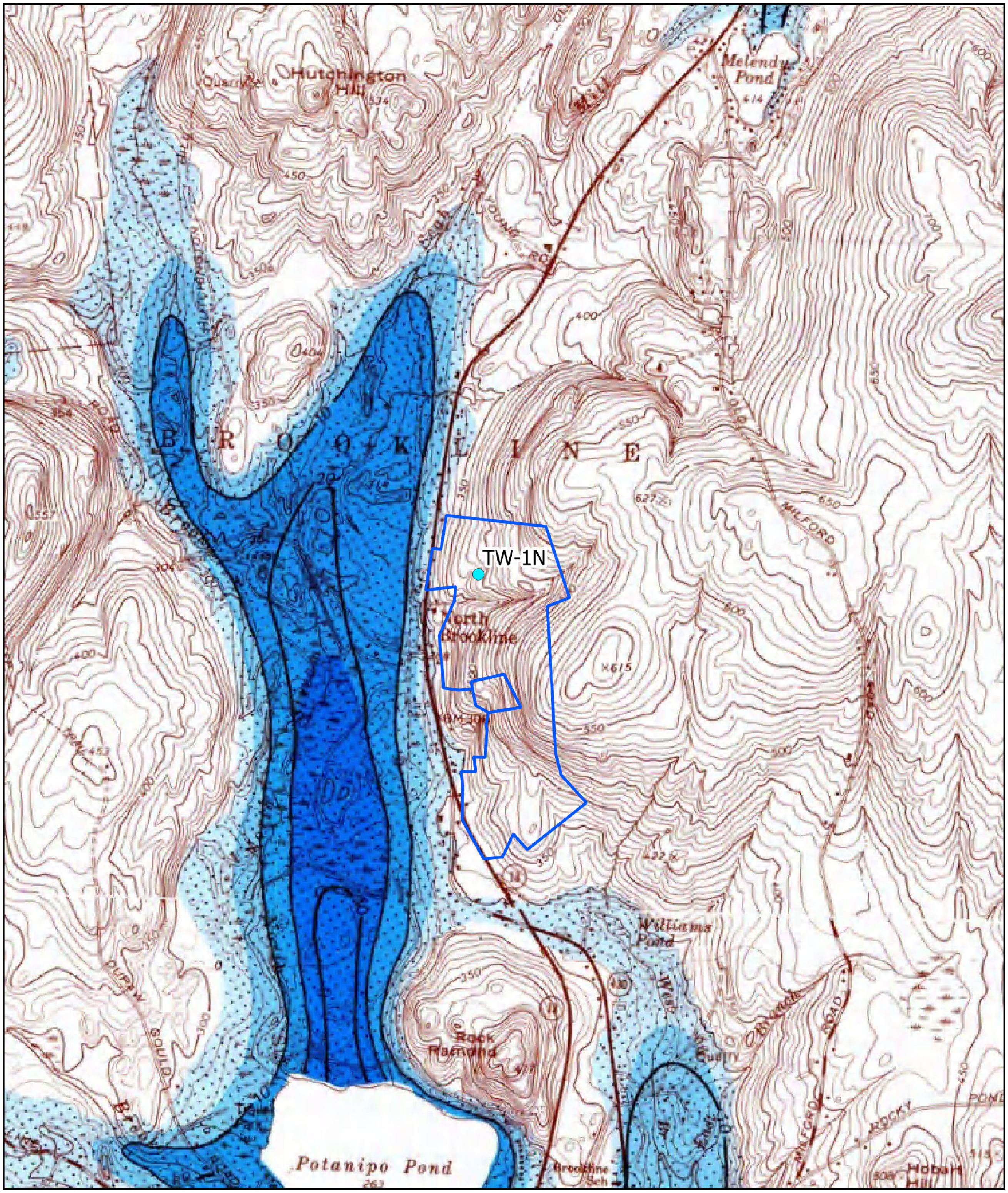


Figure 4 -Potential Impact Directions



From Hydrogeology of stratified-drift aquifers and water quality in the Nashua Regional Planning Commission Area, south-central New Hampshire; WRIR 86-4358 (Toppin, 1987).

Figure 5 - Stratified-Drift Aquifer Map

Recharge

Any assessment of the sustainability of a groundwater extraction requires consideration of recharge. All water pumped from a bedrock well ultimately is derived from water originating at the surface, whether it is direct infiltration of precipitation falling on the ground surface, or leakage of water from streams and lakes into the underlying sediments, and from there into fractures at the bedrock surface.

Brookline receives about 47 inches of precipitation in an average year, according to several internet sources. BOL owns two contiguous lots at the site. The main lot, D-50, has an area of 121.7 acres, and the smaller lot, D-70, covers 4.5 acres. Their combined size is about 126 acres.

If all of the 47 inches of annual precipitation were available as recharge, the volume falling on a 126-acre property would amount to continuous flow at a rate of 306 gpm. In fact, much of the incoming precipitation will not be available to recharge the aquifer, given that a fraction of the water will be lost to evaporation, plant transpiration, and rapid runoff. Glacial till may permit the entrance of 8 inches of precipitation water per year into underlying bedrock aquifers, based on several studies focused on the Northeastern U. S. A higher infiltration rate is assumed for areas covered by coarser-grained sediments, like glacial sand and gravel, perhaps 12 inches or more per year.

At the BOL site, most of the property is covered by till. The till cover in the southern half of Lot D-50 appears relatively thin, and discontinuous. Bedrock outcrops are common there, and this means that over a fraction of the property there is no low-permeability till layer to inhibit the entrance of precipitation into exposed bedrock fractures, if such fractures happen to be exposed in the outcrop areas. The till appears thicker in the northern part, where no outcrop exposures were found during a site visit. The depth to bedrock was 21 feet at Well TW-1N. In this setting we assume it is appropriate to limit infiltration to an average rate of 8 inches annually. If 8 inches per year of on-site recharge is available to replenish the fractured-bedrock aquifer, that amounts to a continuous inflow rate of 52 gpm over the 126-acre site. Comparing this to the development's average water demand, the demand of 20 gpm represents about 39 percent of potential on-site recharge. This of course ignores recharge of treated wastewater from the development's leach fields.

It should be kept in mind that direct infiltration of precipitation on the project site is only one component of potential recharge. The fractured-bedrock aquifer consists of an interconnected network of fractures, and the fracture network does not terminate at the property boundary. As already explained, the high yield of Well TW-1N implies that the well is connected to a comparatively extensive fracture system, and the strong NNE-trending lineament that passes through the property at the well site marks an especially obvious candidate structure that may be partly responsible for the well's high yield. If this feature persists to the southwest under the gravel-filled valley of North Stream and Scab Mill Brook west of Route 13, it would have the potential to receive recharge from the water-saturated sediments.

Moreover, it should be kept in mind that flow of water from the sediments of the gravel-filled valley to bedrock wells on the subject property will not be carried only by the kind of major geologic structures that tend to be marked by lineaments. Flow can also be expected to take place through a network of interconnected fractures that are distributed more widely through the rock mass. It is also worth noting that all of the bedrock wells in this area have the potential to derive recharge from the saturated sand and gravel deposits in the valley.

Aquifer Recharge by Septic Systems

The average predicted water withdrawal from the aquifer of 20 gpm does not represent a purely consumptive use. Much of the water pumped from the development's supply wells will ultimately be returned to the aquifer, so that the net water withdrawal on average will be considerably less than 20 gpm. Help in estimating the quantity of water that would potentially be returned to the aquifer came from a 1999 report published by the American Water Works Association Research Foundation, "Residential End Uses of Water" (Mayer et al., 1999).

The report contains data on residential water use by category, and is based on a survey of households in twelve localities. Most of the surveyed localities are in the western United States, in places where water use habits might be expected to differ from those prevailing in northern New England. However, the study included data from Waterloo and Cambridge, Ontario, where the annual precipitation rate and temperature range are more like those in Brookline. The survey included data from 95 households in these communities.

The survey allowed for differentiation between indoor and outdoor water uses. Indoor water uses, which would include activities like doing laundry, washing dishes, taking showers, and flushing toilets, all result in disposal of the water being used through the septic system. Thus, all of this treated wastewater is released through leach fields, and then leaks into the unconsolidated sediments under and adjacent to those leach fields. All of this water has the potential to reenter the bedrock aquifer. Some of it, of course, may emerge in wetlands areas or other surface water bodies downgradient from the leach fields, and some of that water may flow out of the area through the natural surface water drainage system. However, that is true for all the water moving through the adjacent surface water bodies. All of that water is nonetheless potentially available to recharge the underlying fractured-bedrock aquifer, by leaking into the fractures that extend to the bedrock surface.

Outdoor water uses include such categories as lawn and garden irrigation, car-washing, and filling of swimming pools. Presumably much of the water used for irrigation is lost to evaporation and plant transpiration, and so is not available for aquifer recharge. Swimming pools may lose between a quarter-inch and a half-inch of water to evaporation each day in season, which for a 15' x 30' pool translates to 105 gallons per day in the summer months. A typical car wash might consume only about 10 gallons, and the amount of aquifer recharge from that water use is likely to be trivial.

The survey showed that in Waterloo and Cambridge, about 90% of water usage was for indoor tasks, and 10% went for outdoor tasks not involving water disposal through the septic system. Given the small fraction of water allocated to outdoor tasks, we can make the simplifying assumption that none of this water ends up as potential aquifer recharge, but that all of the water disposed through the septic system does. This means that the development can be expected on average to pump water out of the aquifer at a rate of 20 gpm, but that the development's leach fields will be returning wastewater that is available as recharge at a rate of around 18 gpm. The net withdrawal from the aquifer would thus be only about 2 gpm.

It should be kept in mind that this analysis ignores seasonal factors. Water withdrawals for consumptive uses like irrigation, pool-filling, and car-washing will peak in the hot summer months, and this might coincide with times when precipitation recharge could be low. However, the main point is that the net groundwater withdrawal associated with the development is considerably lower than the nominal average combined well pumping rate of 20 gpm.

Existing Wells

NHDES has collected information on water wells drilled by NH-certified well contractors since the mid-1980's, and the information can be obtained from the agency's OneStop Database. This information can be useful in assessing the general characteristics of aquifers in particular areas.

The database has entries for 188 bedrock wells within a one-mile radius from Well TW-1N. Five wells tapping unconsolidated overburden are also in the database. The wells were drilled between 1984 and 2020. Table 1 summarizes the main parameters of interest for the bedrock wells. Figure 6 shows the well locations with reported yields, and Figure 7 shows the same wells with their total depths. Note that some yield and depth labels do not appear on the maps because multiple wells were drilled on the same property, and the labels for these may overlap.

Table 1 - Summary of OneStop Database Bedrock Wells

	TD (ft)	Depth to BR (ft)	Casing Length (ft)	Yield (gpm)	SWL (ft)
Count	188	182	183	187	161
Average	545	13	32	16	44
Median	472.5	8	29	6	25
Max	1800	79	110	100	500
Min	85	0	6	0	0

Yield values were reported for 187 wells. The average yield was 16 gpm, and the median yield was 6 gpm. 80 wells had yields of 10 gpm or more. 20 wells had yields of 1 gpm or less, which included 12 wells with a reported yield of zero.

Generally, a yield of one or two gpm is the minimum that is considered adequate to serve a single-family household, but determination of what constitutes an adequate well is a little more complicated than simply considering the well's yield. The well's depth also must be taken into account. A well with a lower-than-average yield must be drilled proportionately deeper, to provide a larger volume of water stored in the well to handle periods of peak demand. NHDES has produced a guidance document with suggestions on the minimum acceptable well depth for a given yield (NHDES, 2019). Review of the NHDES database records show that, for the 172 wells with a reported yield of 0.5 gpm or more, all of them satisfied the NHDES criteria for minimum acceptable capacity (for obvious reasons, the zero-gpm wells did not).

Well depths were reported for 182 wells. The average well depth is 545 feet, the median depth is 473 feet, and well depths range from 85 to 1,800 feet. The average and median values are not unusual for wells tapping metamorphic rocks like the Massabesic Gneiss, and indicate that many well owners did not need to drill to extraordinarily great depths to develop enough water to supply a household.

However, some well owners had to drill to great depths before encountering water-bearing fractures capable of satisfying the needs of a household. Twenty-one wells have a depth of 1,000 feet or more. The average yield of these wells is 6 gpm, and seven of them have a reported yield of zero.

Four of the wells with reported yield of zero gpm were drilled in a cluster on a single property south of the development property, about 4,200 feet south of Well TW-1N. Their depths ranged from 400 to 1,400 feet, and they were drilled between April and October of 1988. After the first four failed well attempts, a fifth well was drilled on the same property in November to a depth of 700 feet, and it had a yield of 10 gpm. It is interesting to note that wells with yields of 100 gpm, 50 gpm, and 40 gpm were drilled within one-quarter mile of this zero-gpm cluster.

The well closest to TW-1N having a yield of zero gpm is 1,700 feet to the east on Captain Seaver Road (Figure 6). That well was drilled to a depth of 1,000 feet in April 1989 before the attempt was abandoned. A second well was drilled on the same property about two weeks later. The second well was drilled to a depth of 1,050 feet, and at that depth hit a fracture with an airlift yield of 50 gpm.

A couple of conclusions can be drawn from the well data. Most homeowners have been able to drill wells with yields higher than those needed to supply a household without drilling to extraordinary depths. However, the Massabesic Gneiss on average has a low frequency of water-bearing fractures. This means that it is occasionally possible to drill a well to considerable depths without developing enough water to support a household water system, but that another well offset only a short distance from the first may have substantial yield.

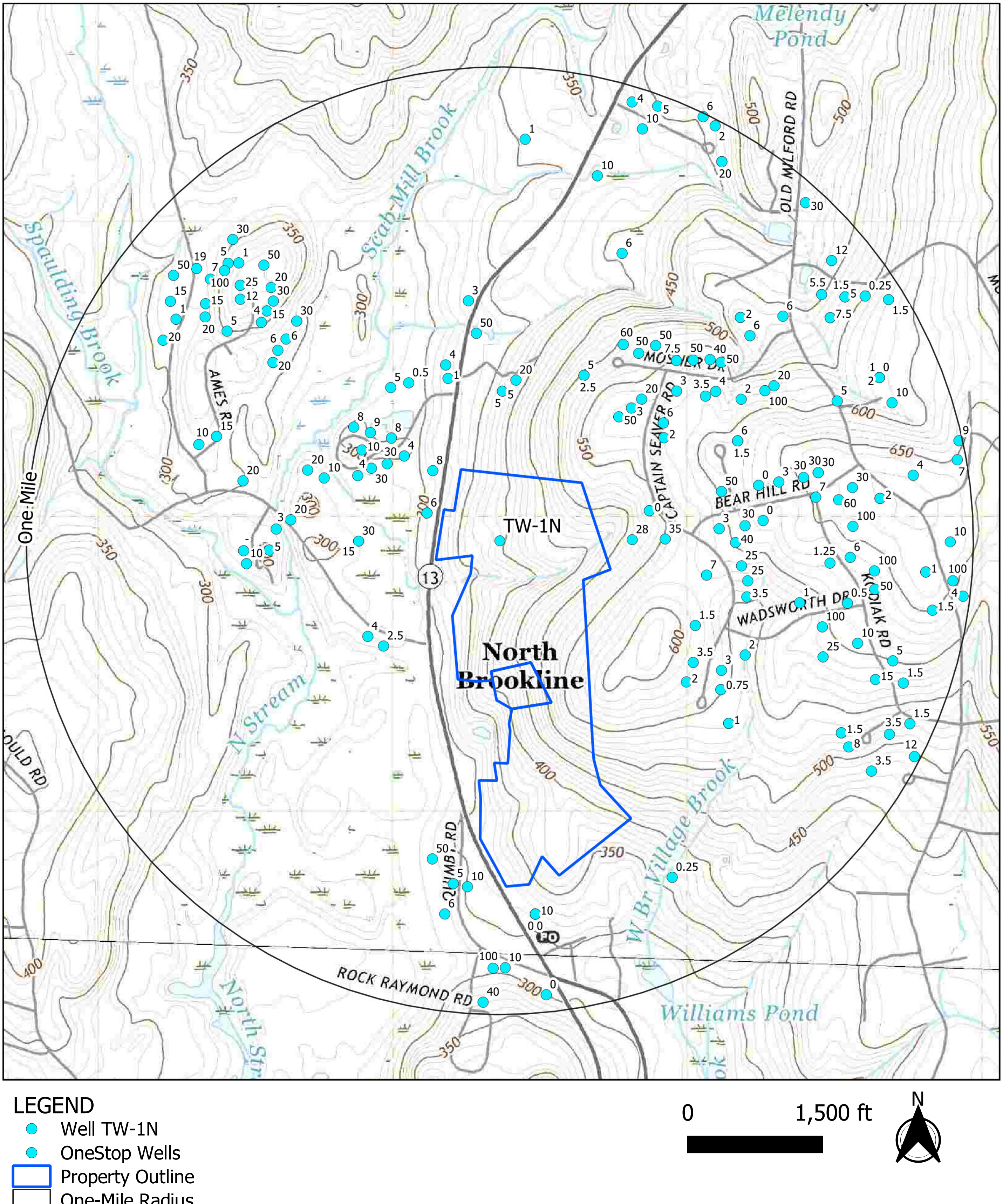


Figure 6 - OneStop Wells: Yield

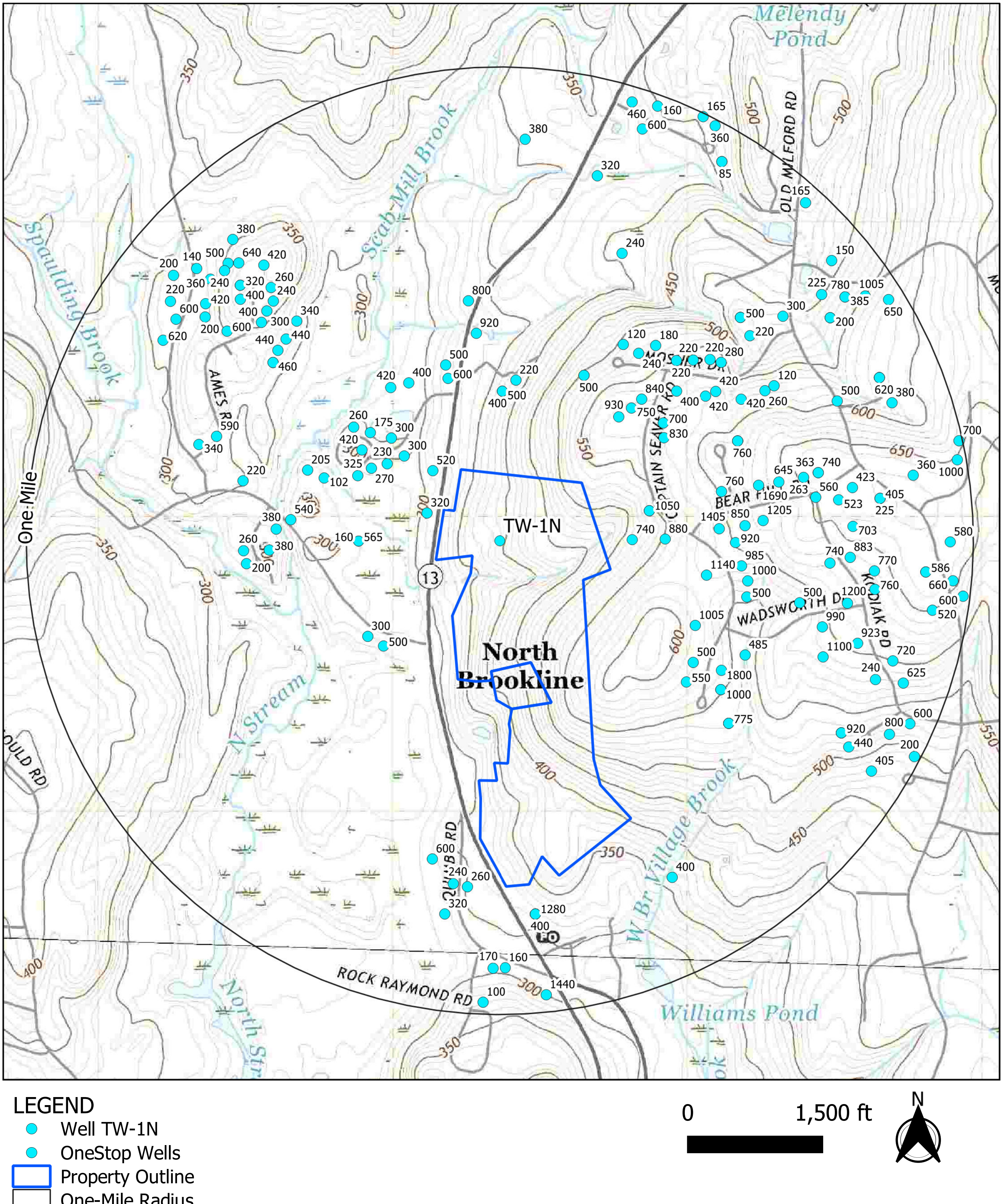


Figure 7 - OneStop Wells: Total Depth

Impacts on Off-Site Wells

The degree of impact that pumping of one well can have on a neighboring well is a function of several factors. These include the flow rate of the well being pumped, the distance between the two wells, certain aquifer parameters (transmissivity and storativity), and the characteristics of the neighboring well. For wells tapping fractured-bedrock aquifers, the orientation and characteristics of individual fractures also have a strong influence (particularly regional-scale structures like those indicated by lineament analysis), as can the structural grain of schistosity developed during regional metamorphism.

Figure 8 is a map showing the approximate distribution of wells within one mile of Well TW-1N. The map includes the wells listed in the OneStop database, along with wells that are inferred to exist based on a survey using Google Earth. A well has been shown for all dwellings or commercial buildings that could be recognized using Google Earth.

The development will be served by Well TW-1N and an adjacent backup well in the north part of the property. Average system demand is expected to be 28,800 gpd, and for the sake of discussion it may be assumed that water will be pumped continuously from one of the wells at a rate of 20 gpm. In response to this water withdrawal, a cone of depression will develop in the water table around the well. The amount by which the water table is depressed will be greatest at the well itself, and the degree of impact will diminish with distance from the well in all directions.

Although we are providing a preliminary opinion on the likely degree of impact to offsite wells in this document, it should be kept in mind that the process of permitting the wells for use as a public water supply under NHDES regulations will require testing that generates the data needed to make offsite impact predictions with much greater accuracy. Each well is to be subjected to a 72-hour pumping test, during which the well will be pumped continuously at 40 gpm (the project's required source capacity, which is double the expected average daily demand).

During this test water levels will be measured in the well being pumped, but also in a representative sampling of available offsite wells that are offset from the pumping well in a range of directions. Water levels will be measured in the offsite wells according to a set schedule (with measurements typically being made once every fifteen minutes by a programmable recording device installed in each offsite well). The measurements will be made during a several-day period preceding the test (to identify background trends in the aquifer), during the test itself, and then during a post-test period to monitor the rebound of the water table after pumping stops.

The data collected during the pumping test is graphed, and the graphs go into a report to NHDES. That report will include an assessment of offsite impacts, and NHDES in making a determination on permitting the new water supply will itself make a judgment on whether the amount of offsite impact (on neighboring wells, and also on natural resources like wetlands) is acceptable.

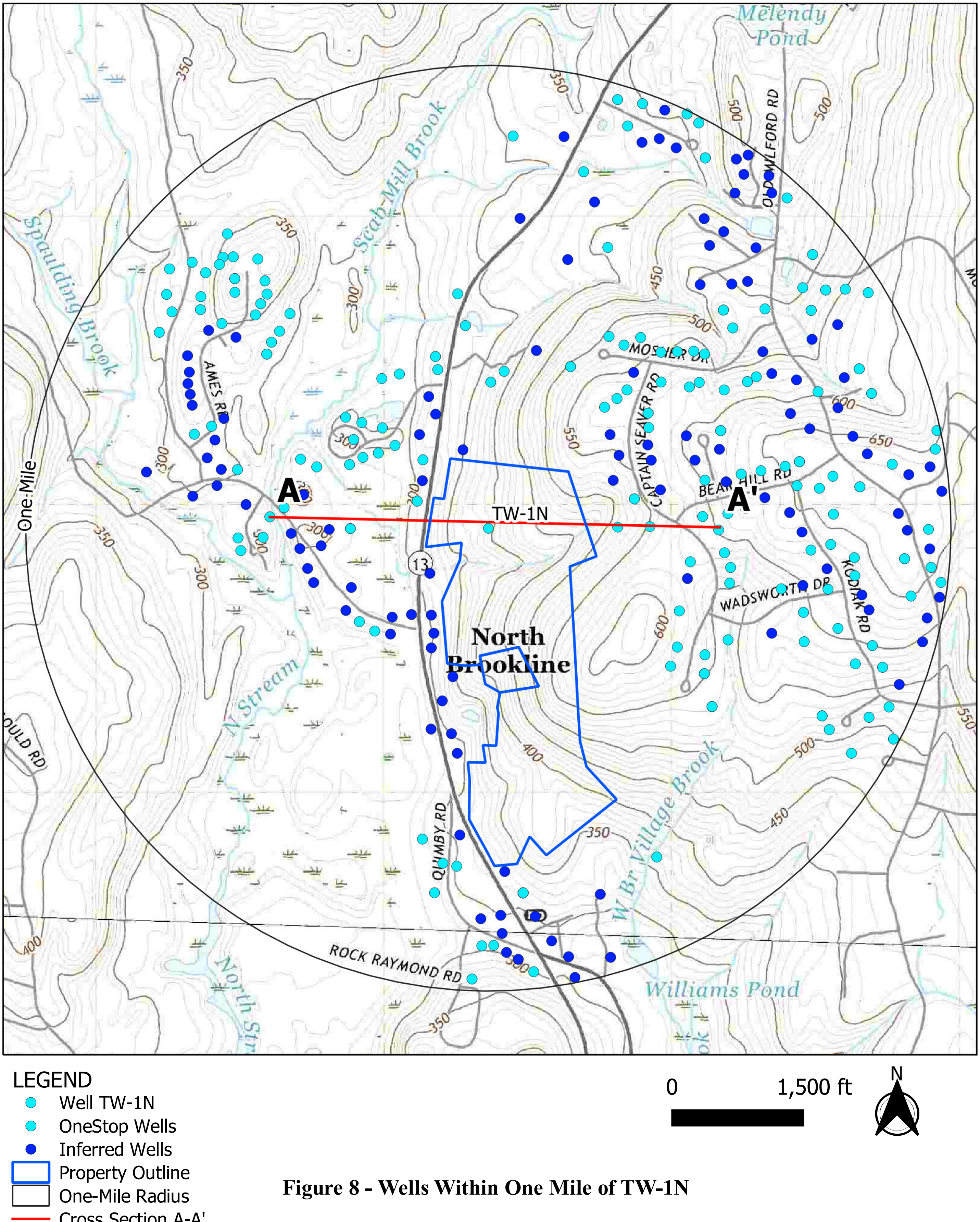
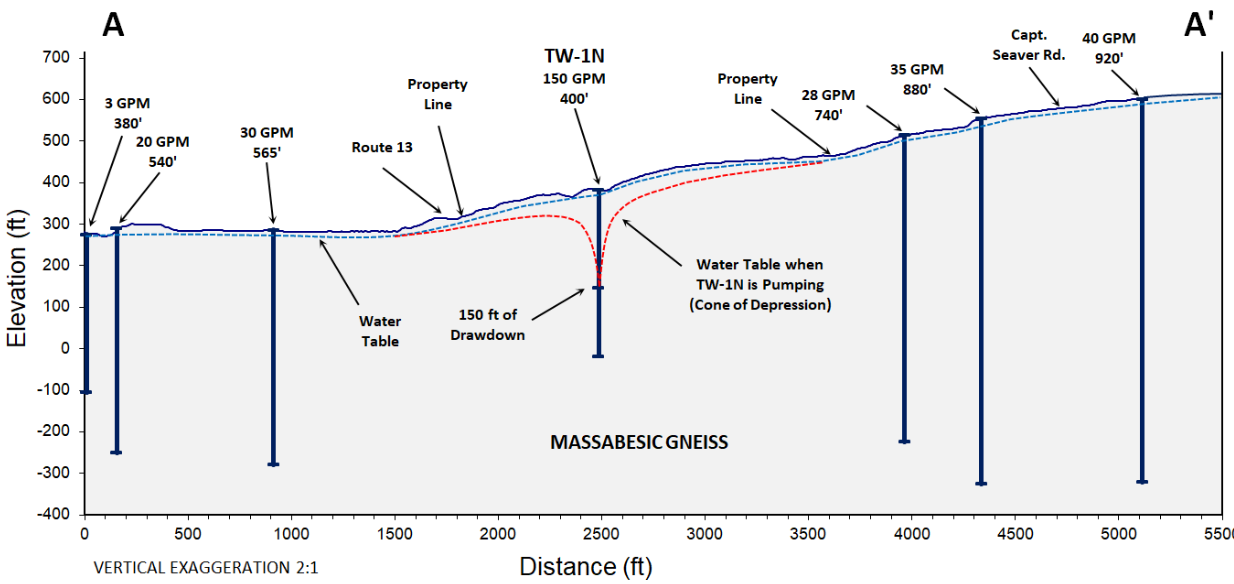


Figure 8 - Wells Within One Mile of TW-1N

Before a formal 72-hour pumping test has been conducted, it is still possible to make subjective predictions about likely impacts based on general knowledge of site geology, the nature of groundwater flow through fractured-bedrock aquifers and on experience at other similar sites. Figure 9 is a schematic cross section through Well TW-1N that may be helpful in explaining offsite impacts. The cross section has an east-west orientation, and its location is shown on Figure 8. Well TW-1N is near the middle of the section. Ground surface elevations were derived from LiDAR elevation data having a resolution of one-half meter. Note that although the cross section in Figure 9 has an east-west orientation, sections at other orientations could have been used just as well to illustrate the principals being discussed here.

Figure 9 - Schematic Hydrologic Cross Section



In addition to Well TW-1N, the section shows six wells from the NHDES OneStop database that are close to the section line. Each well is indicated by a heavy blue line that shows the well's depth, and a label showing the yield and well depth. It was not practical to show the layer of unconsolidated overburden (either glacial till, or sand and gravel) that lies on top of the Massabesic Gneiss at the scale of the cross section. The till layer was 21 feet thick at Well TW-1N, and overburden at the six other well sites ranged from absent (i.e., bedrock is exposed at ground surface) to 39 feet thick.

The inferred shape of the water table is shown by a dashed blue line. Reported water levels in the NHDES database wells ranged from 8 feet to 40 feet below ground surface. In general, the water table can be expected to roughly follow the ground surface, and the water table shown in Figure 9 was drawn to generally conform to that rule.

Also shown is a hypothetical version of the cone of depression in the water table that would form around Well TW-1N in response to sustained pumping at a rate of 20 gpm. To make this diagram, it has been assumed that 180 days of continuous pumping would cause the water level in the well to decline by 150 feet. The single water-bearing fracture encountered in this well occurred at a depth of 389 feet, which means that the assumed decline under pumping conditions would use less than half of the quantity known as "available drawdown," which is the total amount the water level could be drawn down without causing the water level to fall below the depth of the shallowest productive fracture.

Before going on, we should point out that one means of estimating a well's maximum sustainable yield involves considering the fraction of available drawdown that would be consumed after 180 days of continuous pumping. The water level trend established during the final hours of a 72-hour constant-rate pumping test is projected out to 180 days, using the assumption that the trend would persist if pumping continued that long. If less than a specified fraction of available drawdown would be consumed (perhaps two-thirds) at a given flow rate, and the water level recovers at a minimum NHDES-prescribed rate after pumping stops, then the flow rate is accepted as the well's sustainable yield. The duration of 180 days is used because a half-year is considered to be the longest time that the aquifer would normally go without receiving significant recharge from precipitation.

The shape of the cone of depression shown in Figure 9 also uses the assumption that a half-foot of water level decline would be seen in wells at a distance of 1,000 feet from Well TW-1N after 180 days of pumping. It is important to keep in mind that this assumption, and the assumption that the withdrawal will produce 150 feet of drawdown at Well TW-1N, is based on experience with other projects and not on data generated during a pumping test of TW-1N. Nonetheless, we believe these are reasonable assumptions. Aside from that, the general form of the cone of depression is realistic. The slope of the water table is shown as being quite steep in the region immediately surrounding the well. The slope gradually flattens out with increasing distance.

Well TW-1N would be expected to cause negative impacts on a neighboring well if pumping of TW-1N caused the water level in the neighboring well to approach that well's shallowest significant water-bearing fracture. If the assumptions used in estimating the form of the cone of depression are realistic, then pumping of TW-1N can be expected to produce water table declines of perhaps a fraction of a foot in the wells closest to TW-1N. In fact, impacts on the offsite wells shown on Figure 9 might not be detectable.

A second point concerns the depth of the offsite wells. Five of the six wells shown on Figure 9 are deeper than 500 feet. It is likely that these wells are only slightly deeper than the level at which the main water-bearing fracture was encountered in each, and if this is so, it means that the fractures are all deeper than the bottom of Well TW-1N. If that is true, there is no possibility that pumping of TW-1N could depress the water level at any of these wells below the level of their water-bearing fractures.

A third point concerns the reported yields of the OneStop wells. The lowest-yielding well has a reported yield of 3 gpm, and this well is about a half-mile from TW-1N. The other five wells all have yields of 20 gpm or more, considerably more than is needed to supply a single-family household. In general, the higher a well's yield is, the smaller the amount of drawdown that occurs when the well is pumped at any specified rate. This means that even when the drawdown associated with the cone of depression surrounding TW-1N is combined with the drawdown produced by the well pump in the offsite well, the combined drawdown will still not be sufficient to lower the water level to the depth of the productive fractures in these relatively deep wells.

For the reasons given above, pumping of Well TW-1N is not expected to have impacts that would interfere with normal use of offsite wells, at least based on what is known now, and assuming that the wells listed in the OneStop database are representative. After a formal pumping test has been conducted on TW-1N, it will be possible to define the cone of depression more accurately. However, it seems unlikely that results of a pumping test would substantially change the conclusion that offsite adverse impacts are unlikely.

Drought

Although it is necessary to consider the development's impact on surrounding water users during times of normal climate conditions, it is also important to assess likely impacts during a drought. A starting point for making that assessment is to define what constitutes a drought in this region. The worst drought of the past 150 years is probably the dry period that occurred during the early 1960's, and it can be taken as representative. In Concord, the top 10 driest years on record going back to 1868 include the years 1963, 1964, and 1965. The average precipitation rate in those years was 26.9 inches, or 61% of the 44 inches that Concord receives in an average year. Brookline receives 47 inches of precipitation in an average year, and 61% of that is 28.7 inches.

In the calculation in the section on recharge, we made the assumption that leakage through the unconsolidated sediments at the site would amount to 8 inches per year. In calculating drought infiltration, we will assume that this leakage of precipitation will be reduced to 61% of normal during a drought, or 4.9 inches per year. This amounts to annualized recharge on the project property of 32 gpm. A well pumping at a rate of 20 gpm would thus consume 63% of recharge during a severe drought year, though it must also be assumed that the return of treated wastewater to the shallow sediments will be the same in a dry year as it is in a normal one. If we compare the drought-year precipitation recharge to the net withdrawal after accounting for septic system recharge, then the development consumes only about 6% of the expected drought-year recharge.

Conclusions

Well TW-1N has not yet been subjected to the type of hydraulic testing that will be required to determine the well's sustainable yield. However, the well showed an airlift yield of 150 gpm when it was drilled, and experience suggests that the lower permitted yield being sought by BOL for this project is likely to be feasible.

The average yield of domestic wells near Well TW-1N is relatively high, and most nearby wells represented in the NHDES OneStop database satisfy standard NHDES criteria for adequate yield. The frequency of fracturing in the Massabesic Gneiss is low, which means that in some cases and locations it has been necessary to drill multiple wells to considerable depths before an adequate water-bearing fracture was encountered. One consequence of this is that many wells near TW-1N are relatively deep, and this somewhat lessens their vulnerability to hydraulic interference from other wells.

Although it is possible that one or more offsite wells could experience reduced output capacity as a result of withdrawals from Well TW-1N, these are likely to be wells that had some inherent limitation in the first place (e.g., water-bearing fractures that are not sufficiently productive, fractures that are too shallow, or not enough available drawdown). Such wells would have been vulnerable whether Well TW-1N was in operation or not.

Only a few offsite wells are separated from TW-1N by less than 1,000 feet. Reasonable assumptions on the shape and size of the cone of depression surrounding TW-1N suggest that pumping of the well at the planned flow rate should not interfere with normal use of neighboring wells.

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