GEI Consultants

Consulting Engineers and Scientists

July 6, 2022
Project 2201518

Mr. Peter Gardner, President
Dieter & Gardner, Inc.
1641 Route 12
Gales Ferry, CT 06335

Dear Mr. Gardner:

Re: Water Study
Proposed Stoddards Wharf Road Subdivision
Ledyard, Connecticut

This letter report documents the results of a water study performed by GEI Consultants, Inc. for the above-referenced project. The project location is shown in Fig. 1. The water study was performed to address the Town of Ledyard's Subdivision regulation Section 8.5.4, which apply to the project, because greater than 30 homes with individual domestic wells are proposed. The intent of the study is described below, followed by a summary of findings and the study itself.

1. Intent of Water Study

The Town of Ledyard's subdivision regulation, as amended September 30, 2013, Section 8.5.4 specifies the scope of the water study:

> "Water studies shall address the adequacy of ground water supplies and the effect of the proposed subdivision on existing surrounding wells".

The regulations for Open-Space Subdivisions (Section 4.9.7, Yield Formula) while not regulatorily applicable to this application, are instinctive as to the analysis to be performed:

> "…evidence the fact that there is sufficient groundwater recharge located within or contributing to the area of the open space subdivision to support the number of supply wells, including community wells, which will be drilled in conjunction with the development of the open space subdivision and all other existing potable water supply wells located within the sub-watershed in which the open space subdivision is being proposed."

Section 8.5.4 requires the study be prepared by a certified geohydrologist. While this specific credential does not exist by name, section 4.9.7 requires a Professional Engineer (P.E.) stamp, which is affixed to this letter, which has been authored by a P.E. specializing in hydrogeology.

GEI Consultants, Inc.
455 Winding Brook Drive, Suite 201, Glastonbury, CT 06033
860.368.5300

Based on the information above, the scope of the subject water study was derived to include:

- Hydrogeologic Characterization.
- Water balance specific to the property on which the subdivision is proposed.
- Water balance for northern portions of the Great Brook and the Avery-Billings watersheds. The project-specific water contribution area includes portions of both watersheds (Fig. 2), from which contributions from both portions were combined for the water budget analysis.
- Drawdown analysis to estimate water level changes adjacent to the proposed subdivision.

2. Summary of Findings

In summary, multiple lines of evidence indicate that an adequate supply of groundwater is present to support the subdivision as proposed, with minimal effect on surrounding wells. The following key concepts are noted:

- **Hydrogeologic Characterization:** The watershed basin is predominantly undeveloped, allowing for replenishment of the aquifer. The proposed subdivision is in a low-lying area where a gravel aquifer is fed by streams and ponds, which would in turn recharge the bedrock aquifer from which the domestic wells will be installed. A geologic fault runs along the west side of Billings-Avery Pond (Fig. 2). The fault zone can be expected to have a relatively high density of fracturing which would provide both storage and transmissivity. Domestic well records for the area indicate typical well yields for bedrock for the region.
- **Water Balance, within area of proposed subdivision:** Assuming typical residential demands, the estimated subdivision demand is 7.5 gpm. Bedrock areal aquifer recharge over the footprint of the subdivision is estimated at 4.0 gpm, resulting in a net demand of 3.5 gpm. This demand is expected to be met by flow entering the subdivision footprint horizontally from off-property. In general, the capture zone for any well on relatively low-acreage parcels is likely to extend off-property.
- **Water Balance, for area contributing water to the area of open-space subdivision:** Assuming typical residential and estimated agricultural demands, the project would use approximately 2.4% of bedrock flow to the contributing area that is not otherwise part of the estimated existing demand. This finding is in agreement with a general statement made for a water study in Greenwich, which noted that estimated groundwater consumptive use is small compared to recharge rates (USGS, 2002).
- Based on a modeling analysis presented herein, the subdivision is estimated to cause an approximate one- to five-foot drawdown within the bedrock aquifer at the subdivision property boundary, as estimated by simplifying groundwater flow through bedrock fractures as an equivalent homogeneous aquifer.

We qualify the findings primarily based on uncertainties inherent in estimation of groundwater flow through fractured bedrock. A good bedrock water source depends on sufficient aperture, extent, and connectivity of fractures. Lines of evidence presented in this study suggest a level of confidence that the watershed will provide an adequate water source.

3. Hydrogeologic Characterization

3.1 Geologic Setting

The site is an approximate 9.4-acre undeveloped parcel abutting Stoddards Wharf Road (CT Route 214) to the south, and wetlands alongside Billings-Avery Pond to the north and east. The parcel is relatively level at approximate Elevation 160 feet relative to North American Vertical Datum of 1988 (NAVD). A relief view of the contributing watershed area (described further in Section 3.2), is shown in Fig. 3.

The project site is in the Avalonian Terrane geologic region of Connecticut. Geology in the region comprises undulating till ridges and alluvial or stratified drift-filled valleys, underlain by gneiss and granite bedrock. Alluvium and stratified drift contain predominantly sand, with stratified drift being coarser.

Domestic well logs for five adjacent or nearby residences were reviewed for soil and yield testing observations. Table 1 provides a summary of information found in the logs. Overburden soil (material above bedrock) in the site vicinity was predominantly reported as sand and gravel, with two of the five logs noting “hardpan”, which is likely low-permeability till beneath the sand and gravel. The remaining descriptions note sand, gravel, and cobbles. Measured overburden thickness ranged from 8 to 40 feet. State geologic mapping shows that the site is located on an east-west trending stratified drift valley along Avery Brook as shown in Fig. 4 (Stone, 1992). Stratified drift deposits are generally associated with high potential water yield in the overburden, given adequate thickness of saturated overburden.

Bedrock comprises fractured crystalline rock, in which groundwater flow occurs through fractures. Fracturing can be seen in roadside outcrops occurring in the area. Bedrock serves as the predominant source of groundwater for private domestic wells in Connecticut. Bedrock groundwater is drawn from fractures. USGS (1969) notes that bedrock in the area is fractured to a depth of several hundred feet, and it is along the fractures that most groundwater moves.. Bedrock fracture distribution is generally uneven, making it difficult to predict potential yield. Sheeting joints common to igneous rocks in the area comprise steeply dipping or vertical joints intersecting horizontal tension joints roughly parallel to bedrock surface (USGS, 1969). Fractures have been observed in quarries where zones of close fracturing were separated by intervals of greater distance between fractures (USGS, 1969). Joints generally become scarcer with depth, such that the chance for significant yield at depths greater than 200 to 300 feet below top of bedrock is slight (USGS, 1969). For purposes of this study, a 300-foot-thick aquifer is assumed.

Bedrock mineral type at the site is mapped as Hope Valley Alaskite Gneiss (Figs. 2 and 5), characterized as gray, medium-grained gneiss (Rodgers, 1985). Adjacent bedrock types comprise Mamacoke Formation (gneiss) and the Plainfield Formation (quartzite). USGS (1968) notes that despite mineralogic and petrologic differences, the water yielding characteristics of the various rock types are similar.

The site is adjacent to a north-south trending fault extending from Preston to Noank (Fig. 5). The fault is part of the Lantern Hill fault system (Goldsmith, 1985). Faults are more likely to form buried valleys, which are typically overlain by stratified drift (including as described onsite above) that may contribute to increased bedrock yield (USGS, 1969). Faults can increase yield due to openings along fault joints where differential movement of rock masses have occurred. Increased transmissivity may extend outward along fault-associated joints. The highest bedrock yields reported by USGS were in wells situated close to faults, where wells yielding at least

40 gallons per minute (gpm) were reported (USGS, 1969). The five well records reviewed for this study showed yields ranging from 2 to 5 gpm (Table 1).

3.2 Hydrology

The site is within the Avery Brook watershed, which naturally drains easterly to the Thames River. An east-west trending series of ponds coincides with the east-west trend of the Billings-Avery sub-watershed (Fig. 6). Billings-Avery Pond receives direct runoff from its basin and is expected to receive some groundwater discharge. The site abuts the Great Brook watershed to the south, which drains naturally in a southerly direction to the coastline. Proposed pumping from residential wells in bedrock is expected to draw water in from both watersheds. The area of estimated contribution to the project is shown in Fig. 6, delineated for purposes of this study based on:

- The northern and eastern limits of contribution are assumed to comprise the natural watershed boundary.
- The southern and western limits of contribution were drawn based on topography. Ground elevation at the site and vicinity undulates, with lower-lying areas occurring at similar elevations. This can be seen qualitatively on the relief map in Fig. 3. South and west of the assumed contribution area, greener shades become darker, indicating an increasing decline in elevation.

Surface water in the area is used for regional water supply and is managed by Groton Utilities. Groton Utilities' watershed map is provided as Fig. 7. Groton Utilities withdraws surface water primarily from the Poquonnock Reservoir, which is within the Great Brook watershed and receives water from ponds and reservoirs to the north, including Billings-Avery Pond. Although Billings-Avery Pond's watershed drains to the east, pond water is also diverted south to the Great Brook watershed via a spillway and Stoddards Brook (Fig. 2). Surficial water transfer is not expected to affect water levels in bedrock, as Groton Utilities maintains the pond's levels, and aquifer discharge or replenishment is a function of surface water levels more so than flow direction.

For streams in the lower Thames and southeastern coastal river basins, USGS (1968) reported equivalent annual contribution of stream flow from surficial runoff ranging from approximately 7 to 15 inches per year, with most being in the 11 to 12 range.

3.2.1 Aquifer Recharge

Groundwater in bedrock aquifers is replenished by precipitation infiltrating through soil or directly to fractures at exposed outcrops. Annual precipitation reported for Norwich, Groton, and Westerly ranges from 47.4 to 54.8 inches (2015 US Climate Data). Rainfall or snowmelt transitions to the processes of runoff, evapotranspiration (plant uptake or evaporation), or recharge (infiltration to the water table). In general, about one fourth of annual precipitation becomes recharge. The units of inches per year are generally used to express rainfall and aquifer recharge rates.

Site topography suggests that under natural conditions, horizontal groundwater flow would occur in an easterly direction. Text books such as Fetter (1994) explain vertical flow relative to topography: Groundwater flow is also expected to occur in a downward direction in upslope areas, being driven by recharge. Upward vertical flow is more likely to occur in low-lying areas such as along surface water features, being driven by pressure relief at discharge seepage locations to streams and ponds. Pumping may alter groundwater flow where pumping withdraws water from the deeper aquifer and discharge to the stream is replaced by a greater fraction from septic return flow.

A groundwater model for the Sound View well field in Old Lyme used recharge rates ranging from 7.2 inches/year in areas of till to 22 inches per year in stratified drift (USGS 2005). Leggette, Brashears & Graham (LBG, 2011) reported a conservative bedrock recharge rate of 5 inches per year for a site in Guilford. A comprehensive analysis for Greenwich estimated recharge rates between 3.9 and 7.5 inches per year (USGS, 2002). The Greenwich study estimated recharge using a formula correlating recharge rate with till presence, suggesting that some water discharges before reaching bedrock groundwater.

GEI used a conservative value of 5 inches per year of recharge to the bedrock aquifer for the Project water study. Due to the site's location along a largely undeveloped valley, within a stratified-drift overburden aquifer, and in proximity to surface water, lower rates are not expected. It is assumed that most roof and street runoff discharges to ground surface. The water table is expected to be shallow, within stratified drift at the project location. Assuming a typical recharge rate to the water table of 22 inches per year, a 5 inch per year recharge rate suggests that 25% (conservatively rounded down) to the stratified drift aquifer enters the underlying bedrock aquifer as recharge. This 25% value was applied in the water budget analysis to septic return flow, in which it was assumed that 25% of septic return flow (assumed as 85% of pumping demand per citation in Table 2) recharges downward to the bedrock aquifer.

3.2.2 Hydraulic Conductivity

Hydraulic conductivity (K) is a basic property of soil used in the estimation of groundwater flow rates. Hydraulic conductivity is a proportionality constant expressed in units of feet per day (ft/d). For scale, clays can have a value of 0.001 ft/d or less, and highly productive gravel aquifers may have hydraulic conductivities in the 50-300 ft/d range.

Sand and gravel in the stratified drift beneath the site could potentially have hydraulic conductivities of 50 ft/d or higher, especially along the centerline axis where coarse material would settle out of fast-moving glacial meltwater. Hydraulic conductivity of till has been reported at 0.03 ft/d for compact silty till to 16 ft/d for loose sandy till (USGS, 1968).

It is common to assign hydraulic conductivities to bedrock for simplification and comparison purposes, even though bedrock is not a uniform porous medium. Fractured bedrock can, however, approach similar behavior to porous media at a large enough scale. USGS (1969) reports a typical hydraulic conductivity value of 0.27 ft/d based on a study of 262 wells in the lower Thames/southeast coastal basin region. For the Sound View well field (Old Lyme) model, USGS (2005) reports using bedrock K values of 0.088 to 1 ft/d along hilltops and 0.13 to 0.23 ft/d for valleys. Values ranging from 0.05 to 2.7 ft/d were used by USGS for the Greenwich study (USGS, 2004), where bedrock is of similar granite/gneiss composition. As shown in Fig. 5, the type of crystalline bedrock varies throughout the region. USGS reports that despite mineralogic and petrologic differences, the water yielding characteristics of the various rocks are similar (USGS, 1968). Values of 0.2 and 0.05 ft/d were used in the drawdown analysis presented in Section 4.

4. Water Balance

A water balance analysis is presented in Tables 2 and 3 and described below, in which projected demand is compared to aquifer contributions as described in Section 3.

4.1 Water Demand

Water demand was estimated using a typical value of 75 gallons per person per day. The Connecticut Department of Public Health (DPH, 2009) and LBG (2011) report a usage rate of 75 gallons per day (gpd) per capita, equivalent to long-term average of 300 gpd for an average of four persons per household. For 36 households, the combined long-term average withdrawal for the subdivision would be 10,800 gpd assuming pumping 24 hours per day at a uniform rate.

Actual usage would be cyclical with higher pumping rates during morning and evening demand. Drawdown would be greatest during high demand. Water table recovery would occur during low demand periods.

The majority of domestic pumpage would recirculate to the shallow aquifer as return flow from septic systems. LBG (2011) reported a 15% consumptive use rate (car washing, lawn irrigation, recreation) that would not be returned to the aquifer.

For the water budget analysis (following section), water demand for all households, existing and proposed, was set at the same value and number and persons per household. It is assumed that all residential homes being serviced by domestic wells are single-family. Agricultural water use in the basin was estimated based assumed low levels of horse and livestock husbandry, using literature-based water demands as described in Table 3. Aerial imagery and roadside observations in the area showed no indication of significant agricultural or industrial operations warranting additional itemization of water withdrawals.

4.2 Water Budget Analysis

Tables 2 and 3 present a breakdown of demand and recharge. Table 2 is a summary comparison of inflow and outflow to the aquifer expressed as gpm). Table 3 shows unit flow rate demands used to compute total flows in Table 2. The source for other inputs (recharge, septic, rainfall, and stream flow) is described in Section 3.

In Table 2, the difference between inflow and demand is calculated, where inflow is estimated to exceed demand, with the difference is tabulated as bedrock surplus flow. Bedrock available flow represents water in the bedrock aquifer that is not otherwise used for water supply.

- **Within area of proposed subdivision:** The estimated subdivision demand is 7.5 gpm. Bedrock aquifer recharge over the footprint of the subdivision is estimated at 4.0 gpm, resulting in a net demand within the subdivision footprint of 3.5 gpm. This demand is expected to be met by flow entering the subdivision footprint horizontally from off-property but within the contribution area. In general, the capture zone for any well on relatively low-acreage parcels is likely to extend off-property.
- **Area contributing water to area of affordable housing subdivision:** The proposed subdivision is predicted to use about 2.4% of available flow in the basin, including septic return flow.

Based on the water budget described herein, the subject parcel and contributing areas appear to have an adequate quantity of water available to support the proposed subdivision in addition to existing surrounding demand. This finding is in agreement with a general statement made for a water study in Greenwich, which noted that estimated groundwater consumptive use is small compared to recharge rates (USGS, 2002).

Surface water losses due to increase groundwater usage are considered insignificant for this analysis. Groton Utilities' safe yield for the Great Brook reservoir system is 12.6 mgd, with average uses in the 5.6 to 5.8 mgd range. The estimated withdrawal from the proposed subdivision, is 7.5 gpm or 0.01 mgd, which is approximately 0.09 % of the reservoir system's 12.6 mgd yield.

4.3 Drawdown Analysis

GEI's approach to assess the effect of domestic pumping was to construct a computer model using the open-source USGS computer code MODFLOW, which solves groundwater mass balance flow continuity equations. MODFLOW is an industry standard program used for groundwater flow computations. A three-dimensional model was created to approximate the bedrock aquifer from which the domestic wells are to pump. MODFLOW is set up by creating a virtual grid, which divides the simulation into cells and layers. The grid is rectilinear across which flow and heads are calculated from cell to cell (as divided by grid lines) subject to boundary conditions (heads along the model borders, aquifer areal recharge, and pumping inputs), and to aquifer hydraulic conductivity. The model was run at steady-state, which represents an average long-term pumping condition.

The proposed subdivision is shown in Fig. 8 along with domestic well locations as simulated. The area modeled is shown in Fig. 9. The modeled area encompasses the estimated water contribution area described above. The model is intended to be a simplification of the bedrock aquifer, in that bedrock is assumed to have a flat surface elevation throughout the model (assigned as elevation 145 feet msl, or approximately 15 feet below ground onsite). The model is intended to have sufficient inputs to represent the approximate flow conditions and available water specific to the site and abutting areas. In the model, an east-to-west flow direction was assumed, based on general topography of the watershed.

Three simulations were performed: Present Conditions, Baseline Pumping, and Sensitivity Pumping. The Present Conditions run represents pre-development water levels for comparison to predicted levels under pumping conditions. The Present Condition run also allows visualization of heads to show representativeness. The Baseline Pumping run represents groundwater flow under the most reasonably expected inputs based on interpretation of information presented herein. The Sensitivity Pumping run represents aquifer parameters (recharge rate and hydraulic conductivity) at the lower end of reported ranges, and with pumping at twice the reference levels shown in Table 3.

Parameter	**Baseline Pumping**	**Sensitivity Pumping**
Bedrock Hydraulic Conductivity	0.2 ft./d	0.05 ft./d
Bedrock Aquifer Recharge	5 in./yr.	2 in./yr.
Domestic Pumping Rate	75 gpd/capita	150 gpd/capita

As described earlier in this report, higher recharge rates than those listed above may apply to the overlying stratified drift overburden, however it is assumed that the recharge rate to bedrock is limited by the capacity of bedrock fractures to absorb water from the overlying saturated material. The overburden was represented as an upper model layer with hydraulic conductivity of 25 ft./d. The river, pond, and wetland systems were represented in the model as drain elements, which function to draw off excess groundwater resulting from recharge saturating the aquifer. The model does not include specific offsite pumping wells or septic returns assuming the recharge rate reflects these effects; and in addition, if included separately in the model, the individual effects would cancel each other out in the comparative drawdown calculation (no other changes to basin water use are assumed to occur concurrent with the proposed subdivision). The fault system was not included in the model because hydraulic characteristics of the fault are not known. It is a conservative assumption to not include the fault, because faulting would transmit water more rapidly toward the subdivision area, resulting in less computed drawdown.

MODFLOW computes groundwater levels throughout the model, which can then be presented as groundwater elevation contours. The computed Present Condition contours are shown in Fig. 9.

For the drawdown estimate, a graphical comparison of computed heads was performed. Heads computed for the Pumping Condition were subtracted for those of the Baseline Condition. Plots showing the result are shown in Fig. 10. As can be seen in Fig. 10, the predicted drawdown of approximately 1 foot occurs along the approximate subdivision perimeter. A drawdown of 1 foot is not considered significant relative to the assumed aquifer thickness of 300 feet.

A sensitivity analysis was performed to evaluate the variability in prediction due to uncertainty in calculation inputs, with inputs varied as tabulated above. The sensitivity analysis shows a 5-foot drawdown prediction at the site boundary. In a comparative model run, a drawdown of 5 feet was also predicted by running the sensitivity analysis model but reducing the number of lots from 36 to 30 (removing the northernmost six residences), the threshold requiring a water study. A 5-foot drawdown is considered minor relative to a 300-foot-thick aquifer. It is possible that temporary drawdowns of such magnitude could occur during peak demand.

As described in Section 2, flow of groundwater in fractured bedrock is difficult to predict. Actual drawdown could be greater or less depending on connectivity of the fracture network. As interferences within residential clusters are not known as a concern in the region, the chance for interferences at the proposed subdivision may be higher but potentially offset by the subdivision's location along a stratified-drift valley with expansive ponds and wetlands and the nearby fault system.

At the existing pumping wells shown in Table 1, drawdown corresponding to the sustained yields was generally reported as the same depth as bottom of well. A specific capacity calculation can be used to estimate drawdown based on typical long-term demand. Specific capacity represents yield per foot of drawdown. Assuming, for a typical 300-foot-deep well with a 3 gpm sustainable yield, the specific capacity would be 0.01 gpm/foot of drawdown. A long-term continuous pumping rate of 0.21 gpm (300 gals/day) divided by 0.01 gpm per foot specific capacity results in a long term drawdown in the well of 21feet. Drawdown in individual wells may be greater than that in the adjacent fracture network due to fracture interconnection and well interface inefficiencies. The drawdown contours shown in Fig. 10 represent hydrostatic pressures in the formation, and not necessarily within the wells themselves.

Limitations

Bedrock fracture flow is difficult to predict. As with any bedrock well, performance of individual wells may be affected by connectivity of fractures and interferences from other wells.

The analysis was performed based on the information summarized in this report in consideration of standard hydrogeological concepts. No other representations and no warranty, express or implied, is made. No field testing was performed for this analysis. The water balance and drawdown calculations are simplified representations. The drawings are to the approximate scale as noted, and not intended for design or construction. This letter is for the sole use of Dieter & Gardner and the Ledyard Planning and Zoning Department in making decisions related to permitting approvals for the Project.

We appreciate the opportunity to be of service on this proposed subdivision.

Sincerely,

GEI CONSULTANTS, INC.

Andrew M. Adinolfi, P.E.
Senior Environmental Engineer

Zachary Tyczka
Hydrogeologist

AMA/ZT:bdp
Attachments:

- Table 1. Well Records
- Table 2. Water Balance
- Table 3. Water Balance Inputs
- Fig. 1 – Site Location
- Fig. 2 – Topography and Subbasins
- Fig. 3 – Basin Relief Map
- Fig. 4 – Surficial Geology
- Fig. 5 – Bedrock Geology
- Fig. 6 – Watershed Boundaries and Estimated Area of Contribution
- Fig. 7 – Great Brook Watershed
- Fig. 8 – Drawdown Prediction Locations
- Fig. 9 – Groundwater Model
- Fig. 10 – Bedrock Aquifer Drawdown Prediction

B:\Working\DIETER & GARDNER INC\2201518 Stoddards Wharf Road\01_ADMIN\Water Study\Stoddards Water Study Ltr_2022-07-06.docx

References

DPH (2009). Recommendations to the Connecticut General Assembly for Ensuring the Adequacy and Purity of New Private Drinking Water Wells., Connecticut Department of Public Health, June 30.

ERT (1985). Environmental Review Team Report on Hilltop Acres, Franklin, Connecticut. October 29.

ERT (1989). O'Keefe Property Development, Ledyard, Connecticut. Eastern Connecticut Environmental Review Team Report, September.

Fetter (1994). Applied Hydrogeology, Third Edition. Fetter, C.W. Prentice-Hall, Inc.

Goldsmith (1985). Bedrock Geologic Map of the Old Mystic and part of the Mystic Quadrangles, Connecticut, New York and Rhode Island. By Richard Goldsmith, prepared in cooperation with the State of Connecticut Geological and Natural History Survey.

Korzendorfer (1990). Estimated Use of Water in the New England States, 1990, U.S. Geological Survey, Water-Resources Investigations Report 94-4252, 1995.

LBG (2011). Community Water-Supply Feasibility Study, Guilford, Connecticut. Prepared for: Town of Guilford. Leggette, Brashears & Graham, Inc., March.

Stone et. al., (1992). Surficial Materials Map of Connecticut. Prepared in cooperation with the State of Connecticut Department of Environmental Protection, Geological and Natural History Survey.

Randall (1996). Mean Annual Runoff, Precipitation, and Evapotranspiration in the Glaciated Northeastern United States, 1951-80. U.S. Geological Survey, Open-File Report 96-395, Allan D. Randall, 1996.

Theis (1935). The Relation Between the Lowering of the Piezometric surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage, Trans. American Geophysics Union 16.

Thomas (2008). Surficial Aquifer Potential Map of Connecticut. Compiled by Margaret A. Thomas, Connecticut Geological & Natural History Survey in cooperation with the Aquifer Protection Program, Department of Environmental Protection Program, March.

2015 US Climate Data. Online access, http://www.usclimatedata.com/, July 27.

USGS (1968). Water Resources Inventory of Connecticut, Part 3, Lower Thames and Southeastern Coastal River Basins, United States Geological Survey in cooperation with the Connecticut Water Resources Commission. Connecticut Water Resources Bulletin No. 15.

Rodgers (1985). Bedrock Geological Map of Connecticut, Connecticut Geological and Natural History Survey in cooperation with U.S. Geological Survey.

USDA (1997). Agricultural Resource and Environmental Indicators, 1996-97. U.S. Department of Agriculture, Economic Research Service, Natural Resource and Environment Division. Agricultural Handbook No. 712, July.

USGS (2004). Water Use, Ground-Water Recharge and Availability, and Quality of Water in the Greenwich Area, Fairfield County, Connecticut and Westchester County, New York, Water Resources Investigations Report 03-4300.

Tables

Table 1. Well Records
Water Study
Stoddards Road Subdivision
Ledyard, Connecticut

Address	Static Depth to Water(a,b) ft. bgs	Reported Yield gpm	Depth to Bedrock ft. bgs	Depth of Well ft. bgs	Reported Overburden
81 Stoddards Wharf Rd.	40	3	14	200	Hardpan, Cobbles, Gravel
85 Stoddards Wharf Rd.	20	3	10	400	Gravelly
95 Stoddards Wharf Rd.	25	5	15	100	Gravel
102 Stoddards Wharf Rd.	10	2	8	320	Topsoil, Gravel
110 Stoddards Wharf Rd.	25	2	40	375	Hardpan, gravel, sand

Notes:

ft. bgs = feet below ground surface.

Source: Well construction reports on file with Ledge Light Health District.

gpm = gallons per minute, measured during time of well construction.

a. Water level apparent on well construction report, at time of well construction. Wells installed between 1970 and 1994.

b. Wells listed above are open to bedrock fractures and sealed above bedrock. Water levels shown indicate hydrostatic heads in the bedrock aquifer, assuming that depth to water measurements were taken at hydrostatic equilibrium. Bedrock water levels may be above bedrock surface in elevation, but not necessarily equal to water levels in the surficial aquifer overlying bedrock.

Table 2. Water Balance
Water Study
Stoddards Road Subdivision
Ledyard, Connecticut

	Existing Conditions		Project Conditions		
Component	**Site (g)**	**Watershed**	**Site (g)**	**Watershed**	
Acres:	**9.4**	**1282**	**9.4**	**1282**	**Source**
Flow Rate Units:	**GPM**	**GPM**	**GPM**	**GPM**	
WATER BALANCE FOR BEDROCK AQUIFER					
Outflow (Demand)					
Project - Proposed	--	--	7.5	7.5	See Table 3
Residences - Existing	--	11.3	--	11.3	See Table 3
Agriculture / Other	--	9.9	--	9.9	See Table 3
Total Outflow	--	21.1	7.5	28.6	
Inflow					
Septic Return - Proposed (f)	--	--	1.6	1.6	LBG (2011) (e)
Septic Return - Existing	--	2.4	--	2.4	LBG (2011) (e)
Recharge	2.4	331.1	2.4	331.1	USGS (1968), LBG (2011) (c)
Total Inflow (h)	2.4	333.5	4.0	335.1	
Available Flow (a)	2.4	312.4	-3.5	306.5	
Project Percentage (b)	--	--	**-86.5%**	**2.4%**	
SOURCE WATER BALANCE					
Streamflow Comparison					
Rainfall	23	3179	23	3179	Randall, 1996 (f)
Streamflow	12	1614	12	1614	USGS (1968), Table 5 (d)
Available for GW (b)	11	1565	11	1565	Rainfall minus streamflow

Notes:

a. Calculated as total inflow minus total demand. Represents water in bedrock aquifer not otherwise used for water supply. Negative indicates net demand within project footprint (assumed to be made up by horizontal inflows from adjacent bedrock).

b. Project demand as percentage of bedrock inflow. Negative value indicates net demand, assumed to be met by horizontal inflows from adjacent bedrock.

c. Equivalent to 5 inches/year. Within range used by published models 3.6-7.9 in./yr for deep bedrock (USGS, 2002) and conservative relative to 8-10 in./yr cited by LBG (2011).

d. USGS (1968) reports watershed contribution to stream flow for several streams in the region of 1.16 mgd/square mile, equivalent to 24.4 in./yr leaving watershed as runoff.

e. LBG (2011) assumed 85% of residential water is returned to the aquifer through percolation from leachfields.

f. Ledyard is within the 48-inch per year precipitation average contour presented in this reference.

g. Water balance within footprint of proposed subdivision only.

h. Mass balance includes slight net increase in recharge due to fraction of septic return originating from outside the volume of bedrock represented (e.g. from horizontal inflows, or downward flow from slight additional mounding in overburden (due to septic return) inducing slight increase of inflow to bedrock.

Table 3. Water Balance Inputs
Water Study
Stoddards Road Subdivision
Ledyard, Connecticut

			Residential				
Water Use - Residential	**No. of Lots / Residences**	**Capita Per Address**	**Population Served**	**GPD Per Capita**	**Total GPD**	**Total GPM**	**Source**
Project (Stoddards Wharf)	36	4	144	75	10800	7.5	75 gpd/cap, DPH (2009)
Existing (within Contribution Area)(d)	54	4	216	75	16200	11.3	75 gpd/cap, DPH (2009)
Total Water Use - Residential					27000	18.8	
			Agricultural (b)				
Water Use - Livestock		**Livestock**	**Assumed Heads**	**GPD Per Head**	**Total GPD**	**Total GPM**	
Livestock	--	Dairy	20	30	600	0.42	Korzendorfer (1990) (a)
Horses	--	Horses	20	30	600	0.42	(a)
Water Use - Irrigation		**Crop**	**Irrigated Acres**	**GPD Per Acre**	**Total GPD**	**Total GPM**	
Assumed Potential Irrigation	--	Vegetables	10	1200	12000	8.3	USDA (1997) (c)
Hay Fields	--	Hay	10	0	0	0	Hay field, no irrigation.
Water Use - Other							
Unaccounted (b)	--	--	--	--	1000	0.69	Unaccounted consumptive use (e)
Total Water Use - Agricultural / Other					14200	9.9	

Notes:

a. Assumed typical value for dairy cows. Shees, pigs, beef cow values are lower. Same value assumed for horses.
e. Assumed values for acreages and herd count that will potentially be used for agricultural/husbandry purposes in the amount shown.
c. Assumed 16 in/yr artificial irrigation as reported for Atlantic states
d. 54 residential addresses were apparent on Assessor's map within contribution area, excluding the Ledyard Center town water service area.
e. Allowance per day for unknown water use such as maintenance, incidental evaporation, inefficiency.

Figures

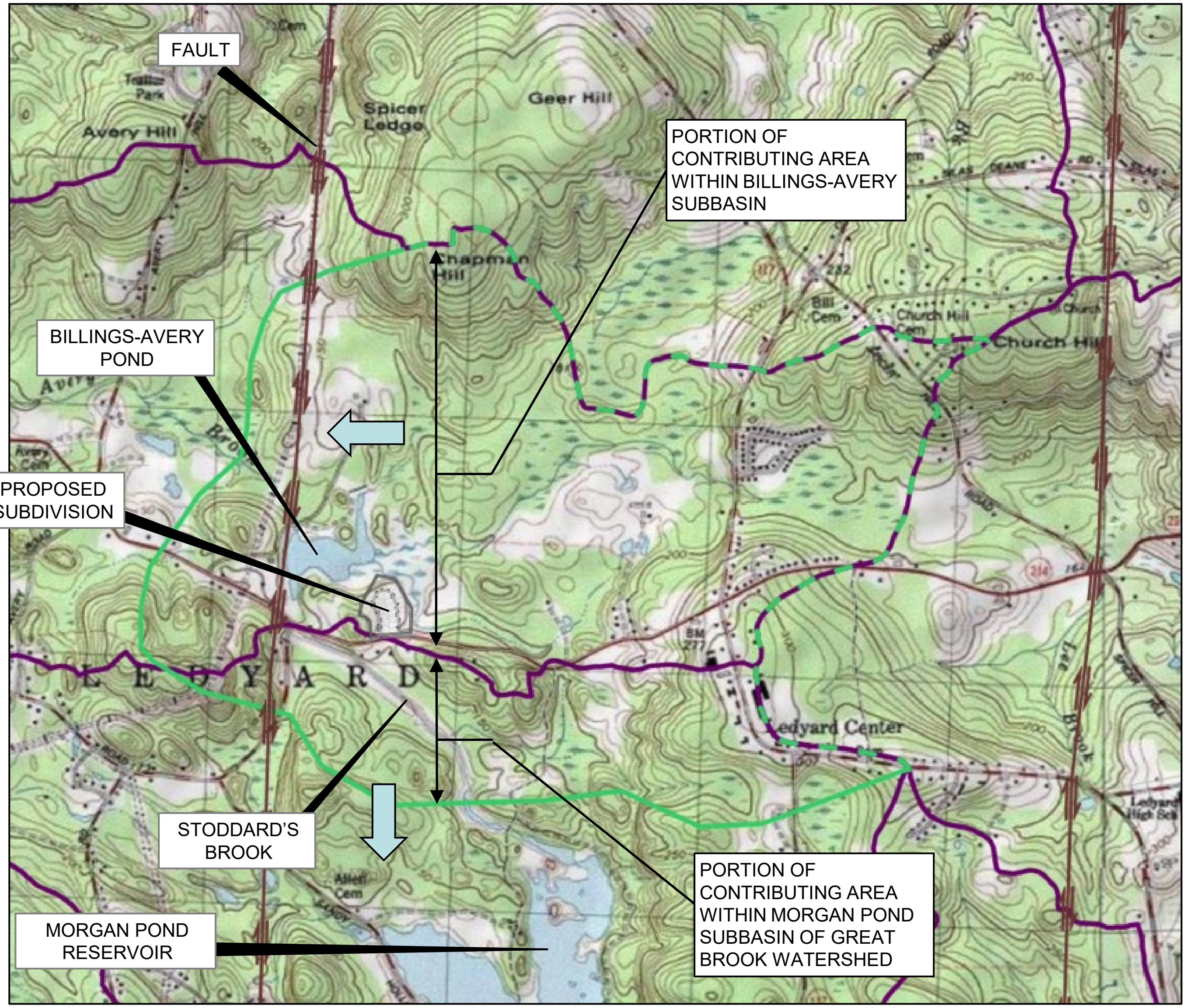
Source: https://www.topozone.com/connecticut/

0 — 1 — 2 SCALE, MILES	WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Site Location**
	AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 1

H:\TECH\project\Regional Modflow model\Report\Figures.pptx

0 2,000 4,000

SCALE, FEET



LEGEND:

CT DEEP DRAINAGE SUBBASIN BOUNDARY (DASHED WHERE COINCIDES WITH CONTRIBUTING AREA).

ASSUMED CONTRIBUTING AREA, SEE. FIG. 7. (DASHED WHERE COINCIDES WITH SUBBASIN BDY).

FAULT

GENERALIZED NATURAL SURFICIAL DRAINAGE DIRECTION WITHIN SUBBASIN

SOURCE:
https://www.topozone.com/connecticut/new-london-ct/city/ledyard-center/

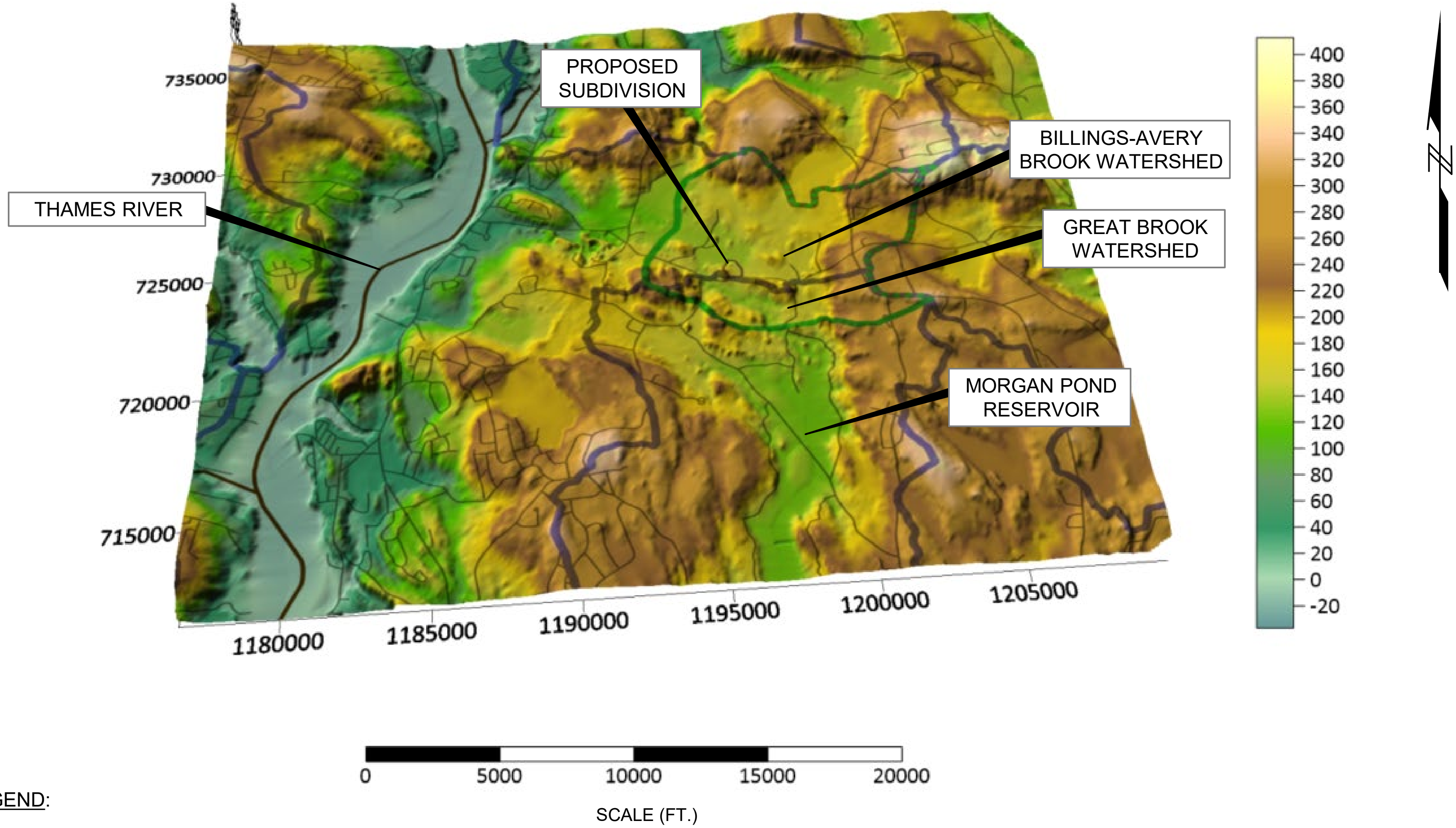
WATER STUDY
STODDARDS WHARF ROAD
LEDYARD, CONNECTICUT

AVERY BROOK PROPERTIES LLC
GALES FERRY, CONNECTICUT

GEI Consultants

Topography and Subbasins

Project 2201518 | July 2022 | Fig. 2



LEGEND:

PROJECT BOUNDARY

CT DEEP DRAINAGE SUBBASIN BOUNDARY

ESTIMATED AREA OF BEDROCK GROUNDWATER CONTRIBUTION (DASHED WHERE COINCIDES WITH DEEP SUBBASINS)

SOURCE:
CT DEEP GIS

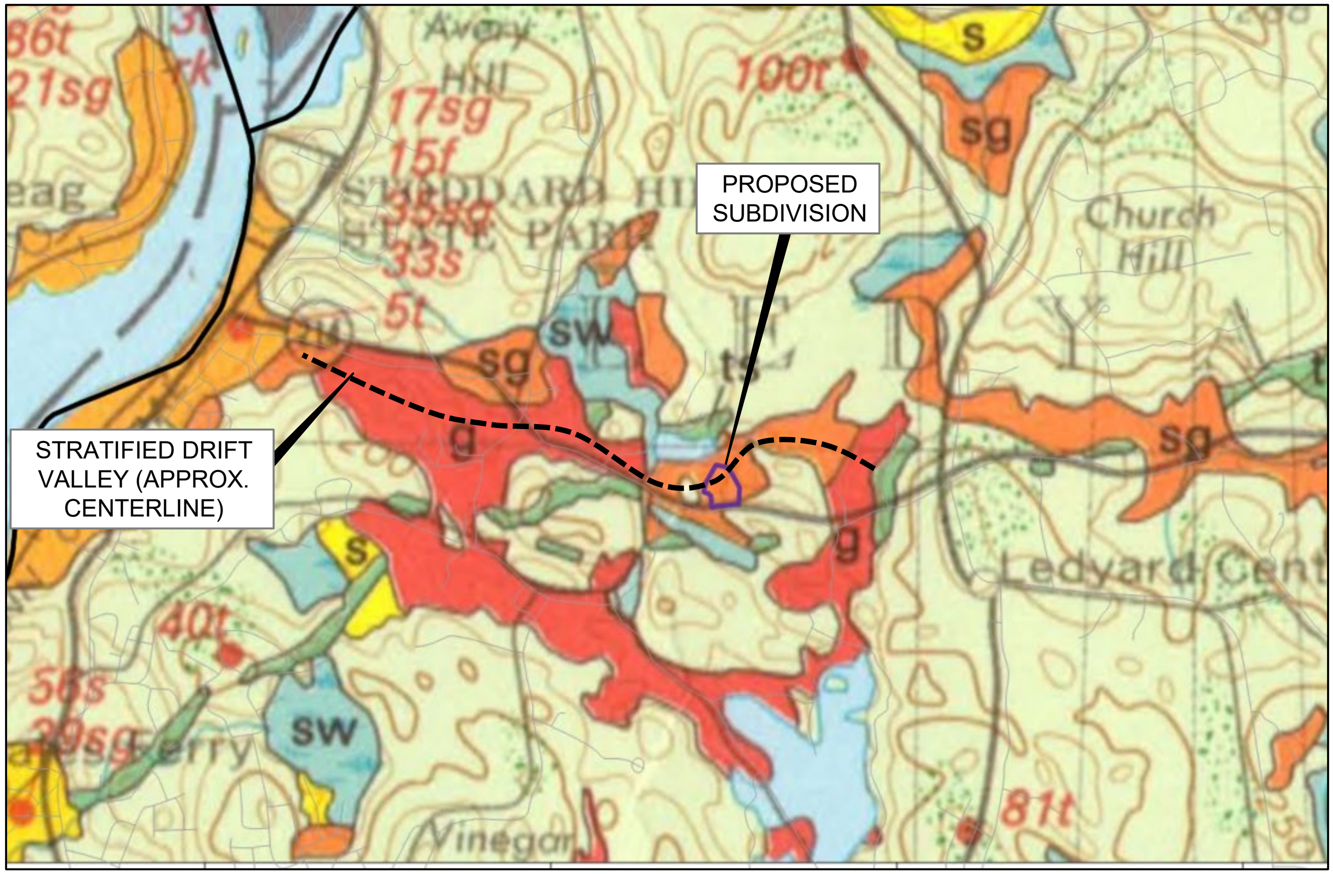
WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Basin Relief Map**
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 3

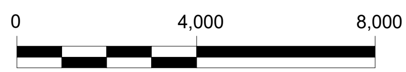
Coarse Deposits

g — **Gravel**—Composed mainly of gravel-sized particles; cobbles and boulders predominate; minor amounts of sand within gravel beds, and sand comprises few separate layers. Gravel layers generally are poorly sorted and bedding commonly is distorted and faulted due to postdepositional collapse related to melting of ice. Gravel deposits are shown only where observed in the field; additional gravel deposits may be expected, principally in areas mapped as unit **sg** (proximal fluvial deposits or delta-topset beds)

sg — **Sand and gravel**—Composed of mixtures of gravel and sand within individual layers and as alternating layers. Sand and gravel layers generally range from 25 to 50 percent gravel particles and from 50 to 75 percent sand particles. Layers are well to poorly sorted; bedding may be distorted and faulted due to postdepositional collapse. It is likely that some deposits within this map unit actually are gravel or sand and gravel overlying sand. It is less likely that some of these deposits are sand (fluvial deposits or delta-topset beds)

s — **Sand**—Composed mainly of very coarse to fine sand, commonly in well-sorted layers. Coarser layers may contain up to 25 percent gravel particles, generally granules and pebbles; finer layers may contain some very fine sand, silt, and clay (delta-foreset beds, very distal fluvial deposits, or windblown sediment)





NOTES:

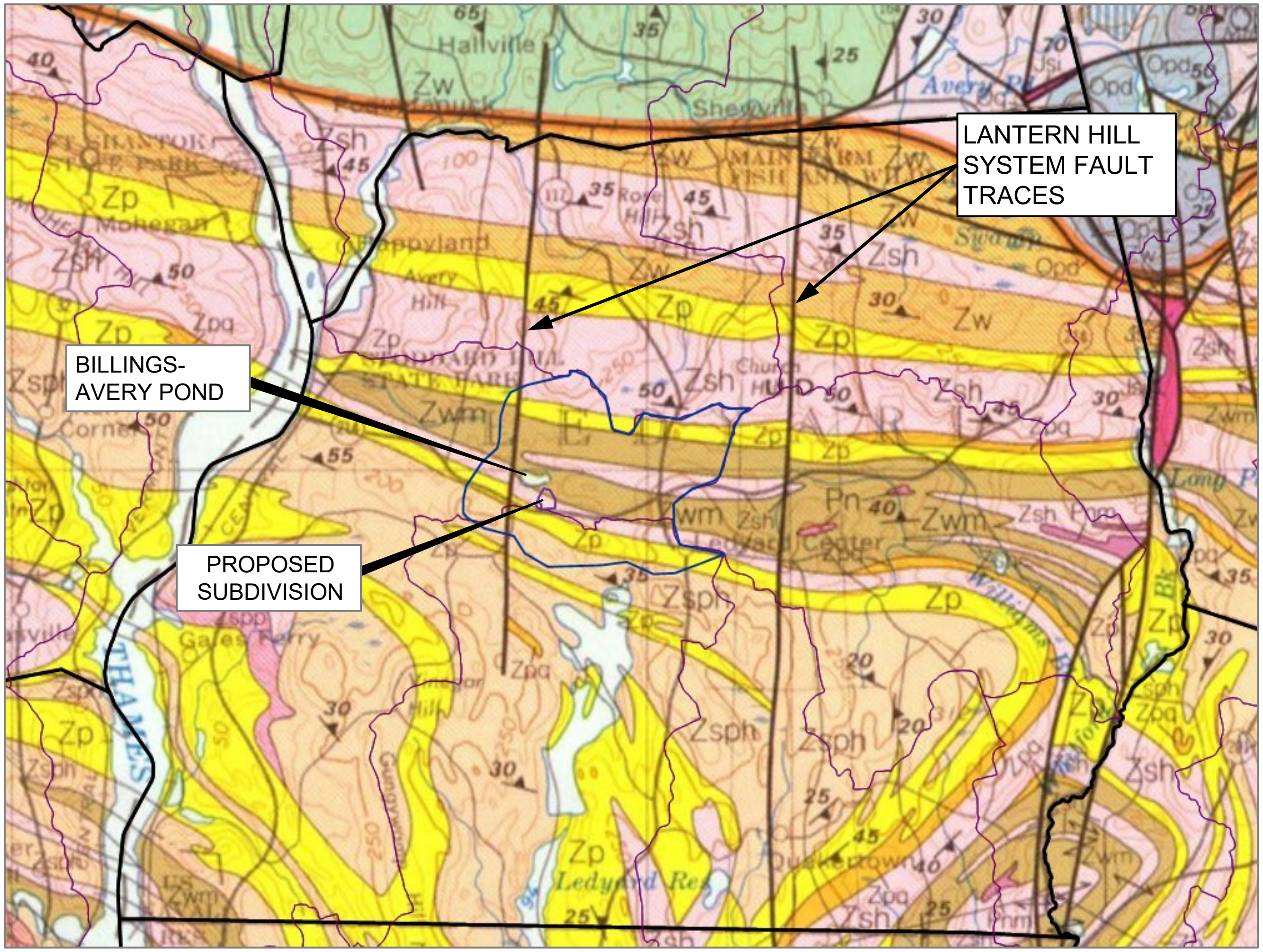
1. ORANGE.RED.YELLOW SHADED AREAS REEPRESENT POTENTIAL HIGH-YIELD OVERBURDEN AQUIFERS
2. NUMBERING INDICATES OBSERVED THICKNESSES OF OVERBURDEN MATERIALS IN FEET

SOURCE:
SURFICIAL MATERIALS MAP OF CONNECTICUT (STONE, 1992).

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Surficial Geology**	
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022	Fig. 4

Bedrock formation

Zp Plainfield Formation
Zpq: Quartzite subunit
Zsh: Hope Valley Alaskite Gneiss
Zsph: Potter Hill Granite Gneiss
Zw: Waterford Group
Zwm: Mamacoke Formation



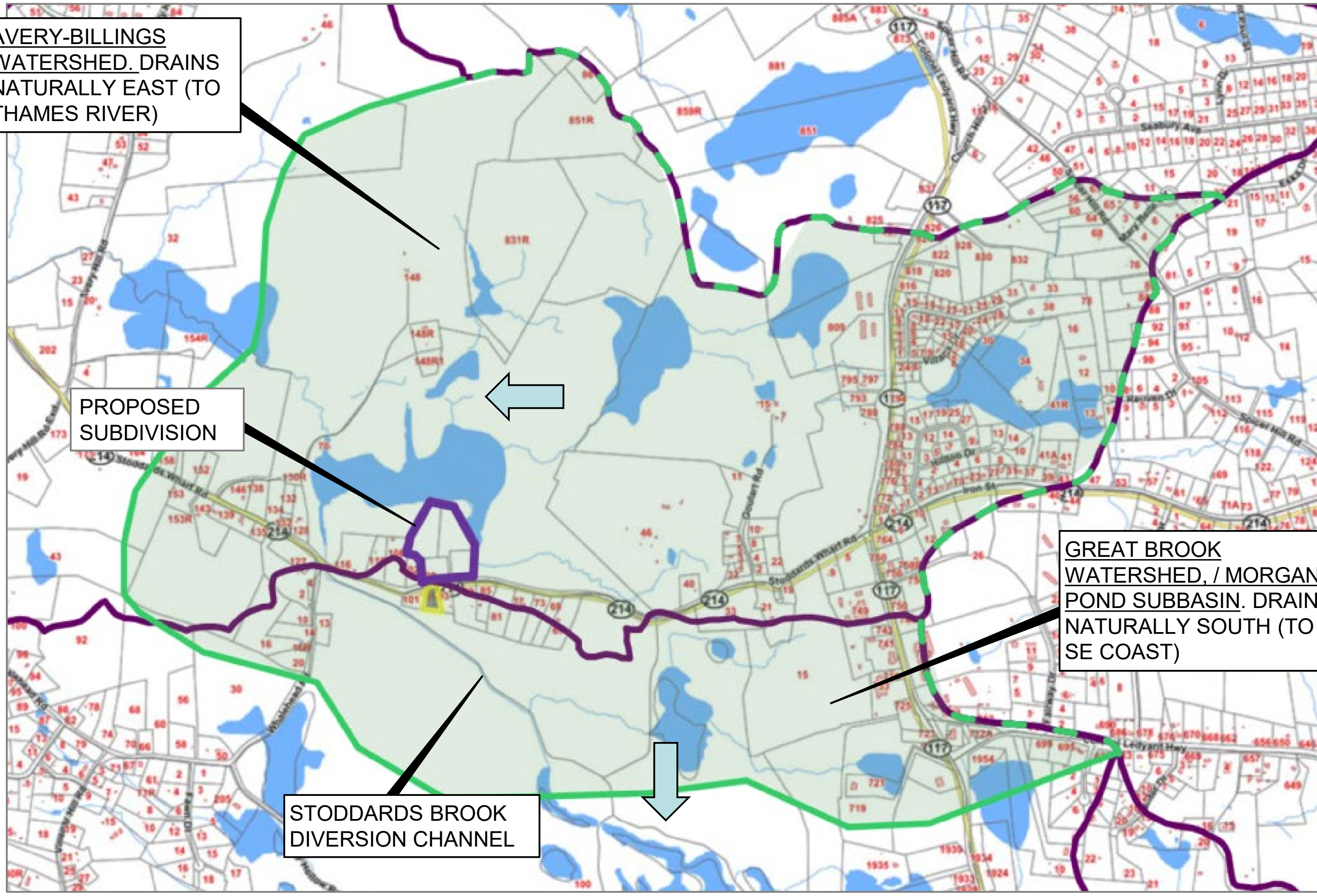
LEGEND:

CT DEEP DRAINAGE SUBBASIN BOUNDARY

ESTIMATED AREA OF BEDROCK GROUNDWATER CONTRIBUTION

SOURCE:
BEDROCK GEOLOGICAL MAP OF CONNECTICUT (RODGERS, 1985). https://ngmdb.usgs.gov/Prodesc/proddesc_54245.htm

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Bedrock Geology**
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 5

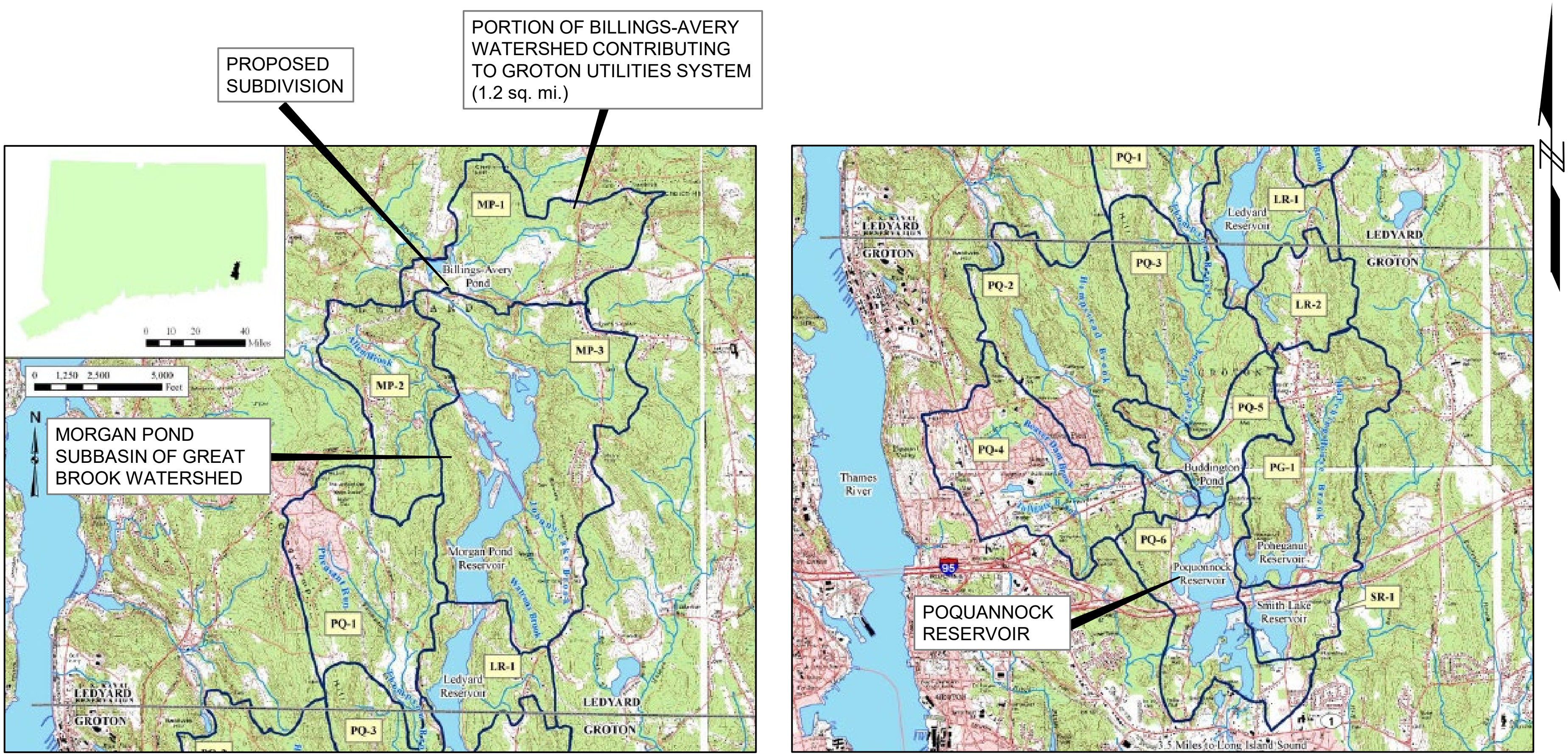


LEGEND:

- PROJECT BOUNDARY
- CT DEEP DRAINAGE SUBBASIN BOUNDARY
- ESTIMATED EXTENT OF AREA CONTRIBUTING WATER TO AREA OF OPEN-SPACE SUBDIVIAION (DASHED WHERE COINCIDES WITH DEEP SUBBASINS)

SOURCE:
TOWN ASSESSORS LOTS, http://www.mapsonline.net/ledyardct/index.html
SUBREGIONAL BASIN POLY OVERLAY, CT DEEP GIS
http://www.ct.gov/deep/cwp/view.asp?a=2698&q=322898&deepNav_GID=1707

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Watershed Boundaries and Estimated Area of Contribution**
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 6



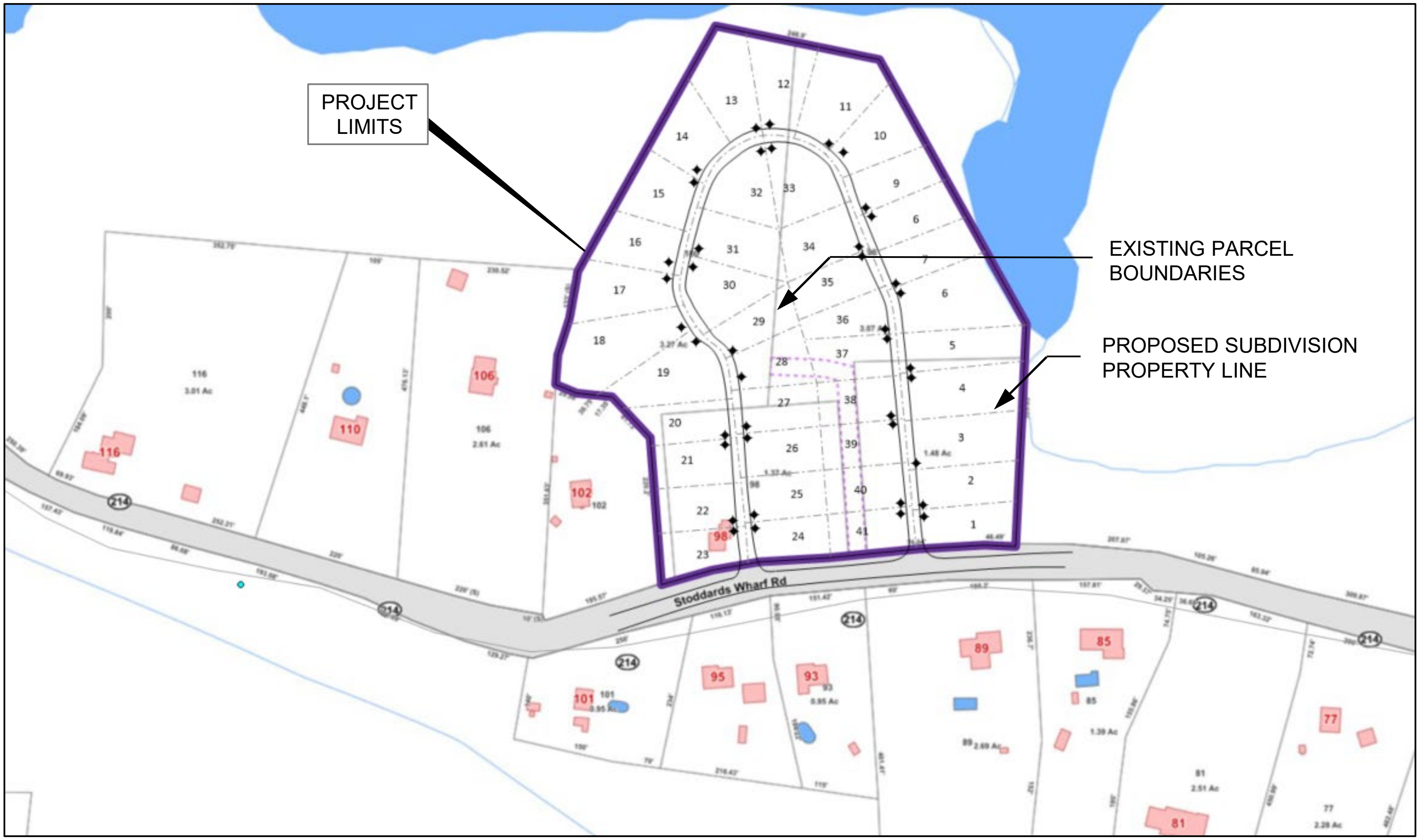
NORTHERN WATERSHED
(LEDYARD)

SOUTHERN WATERSHED
(GROTON)

SOURCE:
MILONE & MACBROOM, INC. SOUTHEAST CONNECTICUT DRINKING WATER QUALITY MANAGEMENT PLAN, Fig. 1, MAY 2008.

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Great Brook Watershed**
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 7

H:\TECH\project\Regional Modflow model\Report\Figures.pptx



LEGEND

CONCPTUAL PROPOSED WELL LOCATION

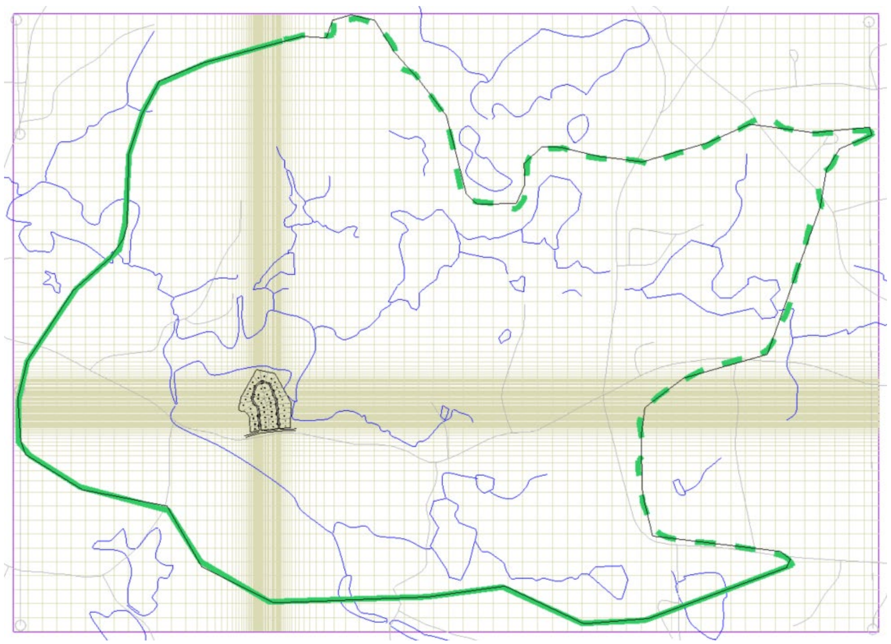
0 200 400

SCALE, FEET

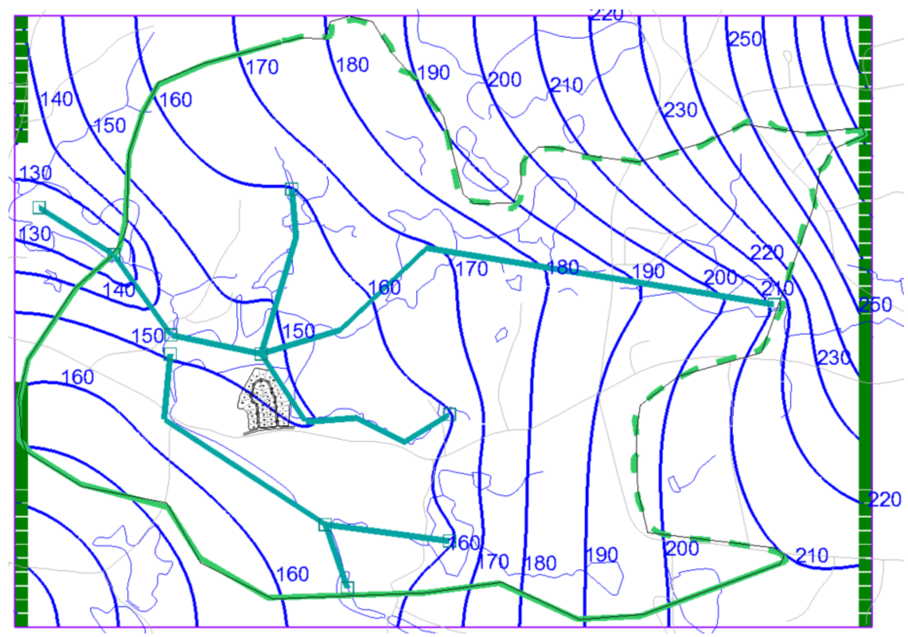
SOURCES:

1. "PLAN SHOWING RESUBDIVISION PROPERTY OF AVERY BROOK HOMES LLC STOODARDS WHARF RD. AKA CT ROUTE 214, LEDYARD, CONNECTICUT", DIETER & GARDNER, June 2022.
2. LEDYARD ASSESSORS MAP https://www.mapsonline.net/ledyardct/

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Drawdown Prediction Locations**
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022 Fig. 8



MODEL COMPUTATIONAL GRID



COMPUTED GROUNDWATER CONTOURS (PRESENT CONDITION)

LEGEND:

MODEL EXTENT

GRID COMPUTATION CELLS

ASSUMED CONTRIBUTING AREA (NOT PART OF MODEL CALCULATION), REF. FIG. 6

HEAD BOUNDARY LOCATION. HEAD ELEV. SET TO ROUGHLY MIMIC TOPOGRAPHY

DRAIN BOUNDARY LOCATION. REPRESENTS GROUNDWATER SEEPAGE TO STREAMS. HEAD ELEVS. SET TO APPROX. GROUND ELEVATION AT PONDS/STREAMS.

200 COMPUTED GROUNDWATER CONTOURS (FT. MSL)

STREAM OR LAKED (APPROX. AS MAPPED BY LEDYARD ASSESSORS)

0 2000 4000

SCALE, FEET

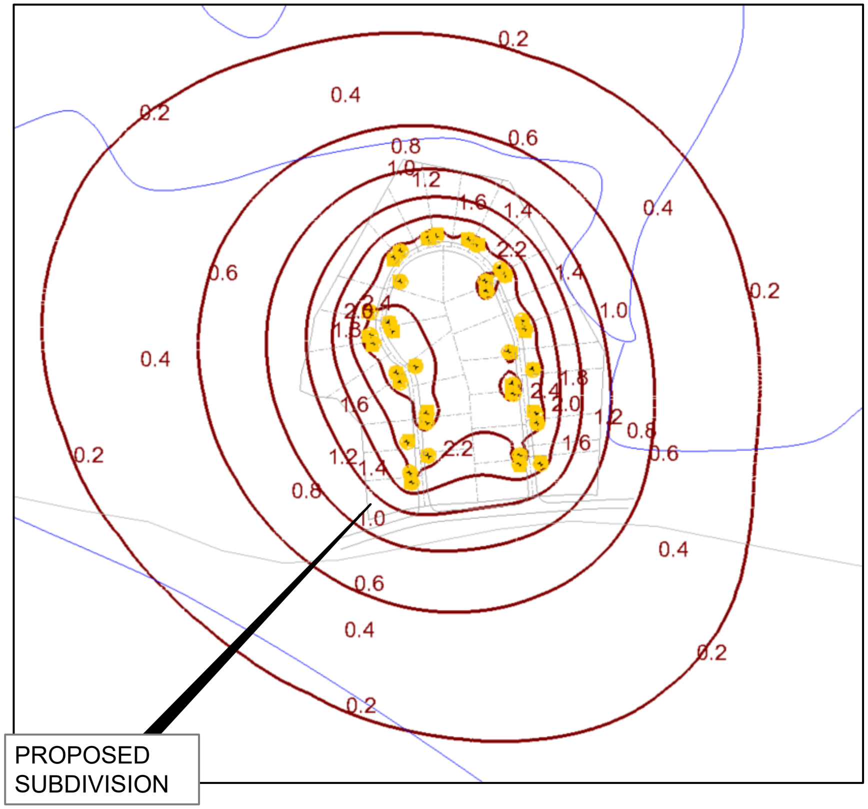
MODEL DIMENSIONS

AREA: 11,500 X 8,200 FT.
TWO LAYERS (ELEV. IN FT. MSL):
TOP LAYER 1: ELEV. 300
(DOES NOT AFFECT CALC.)
TOP LAYER 2: ELEV. 145
(ASSUMED TOP OF BEDROCK ONSITE)
BOT LAYER 3: ELEV. -150
(ASSUMED ~300 FT. THICK VIABLE BEDROCK AQUIFER)
GRID SPACING :
190 FT. AT CORNERS
APPROX. 3-15 FT. INTERIOR ON-SITE

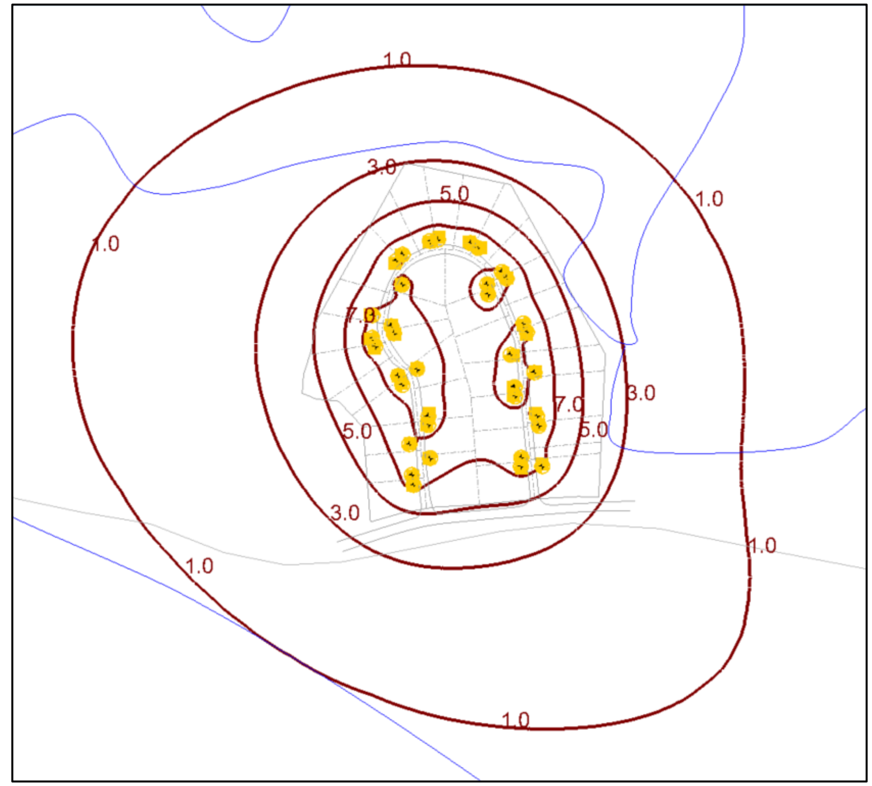
N

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Groundwater Model**	
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022	Fig. 9

H:\TECH\project\Regional Modflow model\Report\Figures.pptx



MODEL PREDICTION (BASELINE)



SENSITIVITY ANALYSIS
(HIGHER PUMPING WITH LOWER PERMEABILITY AND AQUIFER RECHARGE RATE)

LEGEND:

CONTOURS SHOWING FEET OF DRAWDOWN DUE TO PUMPING, RELATIVE TO THE ASSUMED PRESENT-CONDITION STATIC WATER LEVEL.

0 500 1000

SCALE, FEET

WATER STUDY STODDARDS WHARF ROAD LEDYARD, CONNECTICUT	GEI Consultants	**Bedrock Aquifer Drawdown Prediction**	
AVERY BROOK PROPERTIES LLC GALES FERRY, CONNECTICUT	Project 2201518	July 2022	Fig. 10

H:\TECH\project\Regional Modflow model\Report\Figures.pptx