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August 1, 2024
File No. 03.0035410.00

David Morgan
Environmental Planner and Conservation Agent
Arlington Town Hall
730 Massachusetts Avenue
Arlington, Massachusetts 02467

Re: Peer Review of Stormwater Mound Evaluation and Design Groundwater Elevation
Proposed Thorndike Place Residential Development
Arlington, Massachusetts

Dear Mr. Morgan:

In accordance with your request, GZA GeoEnvironmental, Inc. (GZA) performed a peer review of groundwater monitoring and stormwater mounding analysis performed by the BSC Group (BSC) associated with the proposed Thorndike Place residential development in Arlington, Massachusetts (the "Site"). BSC performed their work on behalf of the Applicant (Arlington Land Realty, LLC). This letter report is subject to the Limitations provided in Appendix A.

BACKGROUND

Thorndike Place (the "Project") is a proposed multifamily development in Arlington located south of Dorothy Road. The Arlington Conservation Commission is reviewing a Wetlands Notice of Intent application (NOI) for the Project and is seeking a peer review of associated materials for compliance with Massachusetts Stormwater Standards No. 2 and No. 3, specifically regarding the stormwater groundwater mound analysis.

The proposed development includes 78,629 square feet (1.8 acres) of impervious paved and rooftop area within the 17.7-acre parcel of land. Most of the stormwater runoff will be directed to a large central stormwater infiltration system. That stormwater infiltration system is planned to be 196 feet long, 41.5 feet wide, with the bottom of the infiltration system located 2 feet above the seasonal high groundwater table.

The reported seasonal high "design" groundwater table is elevation 4.0 feet and the bottom of the stormwater infiltration system at elevation 6.0 feet. When the water level in the stormwater infiltration basin rises 1.5 feet (to elevation 7.5 feet) during large storm events it will begin to overflow through a stormwater outlet structure.

In addition, there are five smaller (driveway) stormwater infiltration areas (each with dimensions about 21 feet long and 14 feet wide) located just south of Dorothy Road.

The most recent BSC Site Plans and updated Stormwater Report are dated September 6, 2023. On behalf of the Conservation Commission, Hatch Associates Consultants Inc. (Hatch) peer reviewed those plans and report and provided comments. BSC responded with additional information in letters dated January 24, 2024, February 13, 2024, February 28, 2024, March 13, 2024, April 24, 2024, and June 10, 2024. BSC's June 10, 2024 letter provided additional information on soil testing and estimated seasonal high groundwater levels and an updated groundwater mound analysis.

On behalf of others, Scott Horsley from Water Resource Consultant (Horsley) provided a letter dated May 16, 2024 to the Conservation Commission expressing concerns regarding the seasonal high groundwater elevation and the stormwater groundwater mound analysis. Similarly, Michael Mobile from McDonald Morrissy Associates, LLC (MMA) provided letters dated April 26, 2024, and May 16, 2024, and a draft presentation dated May 2, 2024 expressing the same concerns.

A Hatch letter report dated May 28, 2024 agreed with the BSC design groundwater elevation of 4.0 feet, but expressed additional concern regarding the groundwater mound analysis and the required drawdown time for the smaller (driveway) infiltration systems.

SUBSURFACE CONDITIONS

A total of 13 test pits (TP-1 to TP-13) were performed on behalf of BSC to depths ranging from 6 to 11 feet below grade at the Site. The soil was generally comprised of a sandy loam fill to a depth of about 8 feet underlain by fine sandy loam. For design purposes Hydrologic Soil Group C (silt loam) was used.

DESIGN SEASONAL HIGH-WATER TABLE

The Massachusetts Stormwater Handbook states:

> *Seasonal high groundwater represents the highest groundwater elevation. Depth to seasonal high groundwater may be identified based on redox features in the soil. When redox features are not available, installation of temporary push point wells or piezometers should be considered. Ideally, such wells should be monitored in the spring when the groundwater is highest and the results compared to nearby groundwater wells monitored by the USGS to estimate whether regional groundwater is below normal, normal or above normal.*

Redox features were observed in test pit TP-3 at elevation 3.6 feet and TP-5 at elevation 4.0 feet. These two test pits are located along Dorothy Road in the area where the five smaller (driveway) stormwater infiltration areas are planned. There were no redox features observed in the fill strata in the area planned for the large central stormwater infiltration system. As a result, water levels were measured by BSC in observation wells installed in this area at test pit TP-7 on April 1, 17, and 24, 2024 and test pit TP-9 on April 17 and 24, 2024. The groundwater levels peaked in both wells on April 17, 2024 at elevation 3.5 feet at TP-7 and elevation 4.0 feet at TP-9. Our review of the USGS historical groundwater elevation data at four Middlesex County wells (Wayland MA-WKW-2R, Concord MA-CTW-167R, Acton MA-ACW-158, and Wilmington MA-XMW-78) revealed that the April 2024 groundwater levels were the highest seasonal water levels observed over the past 10 years. Therefore, we conclude that the seasonal high water table elevation of 4.0 feet used by BSC is for "above normal" groundwater conditions and is suitable to be used for stormwater design for this project. As noted above, GZA's opinion on design groundwater elevation findings are consistent with the opinion expressed by Hatch and BSC.

Note that we did not use USGS well Lexington MA-LTW-104 (which was used by MMA and Horsley) in our analysis because that well is in a sand and gravel aquifer with a very shallow water table. Those conditions are not present at the Site. In addition, that USGS well is more effected by individual rainfall events than by seasonal variations of the groundwater table, which is not typical of other USGS wells in the area.

GROUNDWATER MOUND EVALUATION

The Massachusetts Stormwater Handbook states:

> *Mounding analysis is required when the vertical separation from the bottom of an exfiltration system to seasonal high groundwater is less than four (4) feet and the recharge system is proposed to attenuate the peak discharge from a 10-year or higher 24-hour storm (e.g., 10-year, 25 year, or 100-year 24- hour storm). In such cases, the mounding analysis must demonstrate that the Required Recharge Volume (e.g., infiltration basin storage) is fully dewatered with 72 hours (so the next storm can be stored for exfiltration).*

The proposed bottom of the exfiltration system is 2 feet from the seasonal high groundwater table and the system is designed to attenuate the peak discharge from the 10, 25, and 100 year 24- hour storms, therefore a groundwater mounding analysis is required.

The groundwater mound that will develop beneath the stormwater infiltration system is dependent on the horizontal hydraulic conductivity of the aquifer (Kh), the thickness of the aquifer (H), the specific yield of the aquifer (S), the length and width of the infiltration area, the applied recharge rate to the infiltration area, and the duration of discharge.

BSC's latest groundwater mound evaluations are provided in their June 10, 2024 letter report. They used a Kh of 5.4 feet per day, which was based on a Rawls vertical hydraulic conductivity (Kv) of 0.54 feet per day (i.e., 0.27-inches per hour) for silt loam and assuming an anisotropic ratio of 10 to 1 (i.e., Kh to Kv). They also assumed that the initial saturated thickness of the aquifer was 5 feet. The transmissivity (T) of the aquifer is Kh times the saturated thickness, which would be 27 feet squared per day. It is GZA's opinion that the assumed transmissivity (T) of 27 feet squared per day used by BSC is a reasonable value to be used in the groundwater mound evaluation for the soil conditions at this Site. BSC assumed a specific yield (S) of 0.08, which again GZA believes is reasonable for the soil conditions encountered at the Site.

The large main stormwater infiltration system is planned to be about 196 feet long and 41.5 feet wide. Per BSC's Stormwater Report the Required Recharge Volume for the Hydrologic Soil Group C is 1,638 cubic feet. The bottom area of the large stormwater infiltration system is 8,134 square feet. Dividing the required recharge volume of 1,638 by the bottom area of 8,134 results in a static water height of 0.2014 feet (or 2.42-inches).

If the stormwater infiltration system was instantaneously filled with the required recharge volume of 1,638 cubic feet and then discharged out of the system at the Kv design rate of 0.27-inches per hour (0.54 feet per day), it would take 8.96 hours to drain (i.e., 0.374 days). GZA's initial groundwater mound analysis using the Hantush method and the values listed above (Large Infiltration System V-1) is provided in Appendix B and indicates that maximum groundwater mound would be 2.27 feet.

However, it is more likely that the required recharge volume would flow out of the infiltration basin over the duration of one day. GZA's second groundwater mound analysis (Large Infiltration System V-2) assumed the same conditions as the Large Infiltration System V-1 except the duration was one day and the applied recharge was 0.2014 feet per day. The resulting maximum groundwater mound would be 1.85 feet (see Appendix B).

It is GZA's opinion that the Required Recharge Volume of 1,638 cubic feet can be infiltrated into the ground, without causing excessive groundwater mounding. However, for stormwater volumes larger than 1,638 cubic feet the rate of groundwater infiltration will decrease significantly, and the groundwater mound will extend into the bottom of the infiltration system.

When the groundwater mound is below the bottom of the infiltration system the water flows out at a vertical hydraulic gradient of 1.0 feet per foot, which allows flow out at the Rawls Kv rate of 0.54 feet per day (0.27-inches per hour). With the bottom area of 8,134 square feet, the flow out of the infiltration system would be 3.05 cubic feet per minute. However, once the groundwater mound extends into the bottom of the infiltration bed (i.e., after about 1,638 cubic feet of discharge), the hydraulic gradient forcing flow vertically out of the infiltration system will decrease by about an order of magnitude (10 to1 ratio), resulting in flow out of the infiltration system of about 0.3 cubic feet per minute. At that point the flow rate will be similar to flow out of a large diameter well. An example calculation of the decrease in flow rate is provided in Appendix B, assuming a Kh of 5.4 feet per day, initial saturated thickness of 5 feet, a 2-foot separation from the bottom of the infiltration system to the seasonal high groundwater table and a radius of influence of 120 feet.

The BSC Stormwater report indicates that for storms with a 2-year frequency, or larger, the stormwater infiltration system will store up to 10,497 cubic feet of water within the basin (between the stormwater outfall invert elevation of 7.5 feet and the bottom of the infiltration basin at 6.0 feet). Due to the decrease in exfiltration flow rate associated with stormwater mounding (described above), the stormwater infiltration chamber will not empty within the required 72-hour period. Assuming the flow rate decreases to about 0.3 cubic feet per minute, only about 1,300 cubic feet of additional water would drain in the 72-hour period. Also, many of the smaller stormwater events would not exfiltrate within the 72-hour period.

The Massachusetts Stormwater Handbook has a footnote 21 in Volume 3, Chapter 1, page 25 with respect to the "Drawdown within 72 hours" requirement that states:

> *In some cases, the infiltration structure may be designed to treat the Required Water Quality Volume and/or to attenuate peak discharges in addition to infiltrating the Required Recharge Volume. In that event, the storage volume of the structure must be used in the formula for determining drawdown time in place of the Required Recharge Volume.*

As noted above, the Required Recharge Volume is 1,638 cubic feet, but the main stormwater infiltration system has a storage volume of 10,497 cubic feet. It is GZA's opinion that the large main stormwater infiltration system would need to be redesigned to allow drainage of the system within 72-hours to meet the requirements of the MassDEP Stormwater Handbook, and to account for the impacts of groundwater mounding during storm events which result in greater than 1638 cubic feet of stormwater runoff. The redesign should also address peak flow rates that discharge to the stormwater outfall control system.

The five smaller (driveway) stormwater infiltration areas are planned to be 21 feet long and 14 feet wide. Per BSC's Stormwater Report the recharge volume during the 100-year storm event for these systems is up to 883 cubic feet. Dividing that recharge volume by the bottom area of 294 feet results in a water height of 3.0 feet (or 36-inches). Using the Kv design rate of 0.27-inches per hour, it would take 133.3 hours (i.e., 5.55 days) to drain the recharge basin. This exceeds the MassDEP Stormwater Handbook requirement of draining within 72 hours. These smaller infiltration systems would need to be redesigned and then a groundwater mound analysis should be performed to redesign these stormwater management systems.

CONCLUSIONS

GZA agrees with BSC and Hatch that the design seasonal high groundwater elevation for the stormwater infiltrations systems should be 4.0 feet.

Although GZA believes the Required Recharge Volume of 1,638 cubic feet can be infiltrated into the ground without causing excessive groundwater mounding, larger volumes of storm water runoff will not drain within the required 72-hour period. It is GZA's opinion that for stormwater volumes larger than the Required Recharge Volume, the rate of groundwater infiltration will decrease significantly, and the groundwater mound will extend into the bottom of the large main infiltration system. In GZA's opinion both the large main stormwater infiltration system and the smaller driveway stormwater infiltrations systems would need to be redesigned to account for the impacts of groundwater mounding during large storm events and to meet the MassDEP Stormwater Manual's maximum allowable drainage standard of 72-hours.

We trust this information satisfies your current needs. If you have any questions or comments, please feel free to contact the undersigned at (401) 374-2317 or via email at anthony.urbano@gza.com.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

Anthony B. Urbano, P.E.
Senior Project Manager

Steven T. D'Ambrosio, P.E.
Consultant/Reviewer

Todd Greene, P.E. (RI)
Principal

Attachments: Attachment A – Limitations
Attachment B – Calculations

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ATTACHMENT A

LIMITATIONS

USE OF REPORT

1. GZA GeoEnvironmental, Inc. (GZA) prepared this report on behalf of, and for the exclusive use of our Client for the stated purpose(s) and location(s) identified in the Proposal for Services and/or Report. Use of this report, in whole or in part, at other locations, or for other purposes, may lead to inappropriate conclusions; and we do not accept any responsibility for the consequences of such use(s). Further, reliance by any party not expressly identified in the agreement, for any use, without our prior written permission, shall be at that party's sole risk, and without any liability to GZA.

STANDARD OF CARE

2. GZA's findings and conclusions are based on the work conducted as part of the Scope of Services set forth in the Proposal for Services and/or Report and reflect our professional judgment. These findings and conclusions must be considered not as scientific or engineering certainties, but rather as our professional opinions concerning the limited data gathered during the course of our work. Conditions other than described in this report may be found at the subject location(s).

3. GZA's services were performed using the degree of skill and care ordinarily exercised by qualified professionals performing the same type of services, at the same time, under similar conditions, at the same or a similar property. No warranty, expressed or implied, is made. Specifically, GZA does not and cannot represent that the Site contains no hazardous material, oil, or other latent condition beyond that observed by GZA during its study. Additionally, GZA makes no warranty that any response action or recommended action will achieve all of its objectives or that the findings of this study will be upheld by a local, state or federal agency.

4. In conducting our work, GZA relied upon certain information made available by public agencies, Client and/or others. GZA did not attempt to independently verify the accuracy or completeness of that information. Inconsistencies in this information which we have noted, if any, are discussed in the Report.

SUBSURFACE CONDITIONS

5. The generalized soil profile(s) provided in our Report are based on widely-spaced subsurface explorations and are intended only to convey trends in subsurface conditions. The boundaries between strata are approximate and idealized, and were based on our assessment of subsurface conditions. The composition of strata, and the transitions between strata, may be more variable and more complex than indicated. For more specific information on soil conditions at a specific location refer to the exploration logs. The nature and extent of variations between these explorations may not become evident until further exploration or construction. If variations or other latent conditions then become evident, it will be necessary to reevaluate the conclusions and recommendations of this report.

6. Water level readings have been made, as described in this Report, in and monitoring wells at the specified times and under the stated conditions. These data have been reviewed and interpretations have been made in this report. Fluctuations in the level of the groundwater however occur due to temporal or spatial variations in areal recharge rates, tidal fluctuations, soil heterogeneities, the presence of subsurface utilities, and/or natural or artificially induced perturbations. The observed water table may be other than indicated in the Report.

COMPLIANCE WITH CODES AND REGULATIONS

7. We used reasonable care in identifying and interpreting applicable codes and regulations necessary to execute our scope of work. These codes and regulations are subject to various, and possibly contradictory, interpretations. Interpretations and compliance with codes and regulations by other parties is beyond our control.

SCREENING AND ANALYTICAL TESTING

8. GZA collected environmental samples at the locations identified in the Report. These samples were analyzed for the specific parameters identified in the report. Additional constituents, for which analyses were not conducted, may be present in soil, groundwater, surface water, sediment and/or air. Future Site activities and uses may result in a requirement for additional testing.

9. Our interpretation of field screening and laboratory data is presented in the Report. Unless otherwise noted, we relied upon the laboratory's QA/QC program to validate these data.

10. Variations in the types and concentrations of contaminants observed at a given location or time may occur due to release mechanisms, disposal practices, changes in flow paths, and/or the influence of various physical, chemical, biological or radiological processes. Subsequently observed concentrations may be other than indicated in the Report.

INTERPRETATION OF DATA

11. Our opinions are based on available information as described in the Report, and on our professional judgment. Additional observations made over time, and/or space, may not support the opinions provided in the Report.

ADDITIONAL INFORMATION

12. In the event that the Client or others authorized to use this report obtain additional information on environmental or hazardous waste issues at the Site not contained in this report, such information shall be brought to GZA's attention forthwith. GZA will evaluate such information and, on the basis of this evaluation, may modify the conclusions stated in this report.

ADDITIONAL SERVICES

13. GZA recommends that we be retained to provide services during any future investigations, design, implementation activities, construction, and/or property development/ redevelopment at the Site. This will allow us the opportunity to: i) observe conditions and compliance with our design concepts and opinions; ii) allow for changes in the event that conditions are other than anticipated; iii) provide modifications to our design; and iv) assess the consequences of changes in technologies and/or regulations.

ATTACHMENT B

CALCULATIONS

Large Infiltration System V-1

This spreadsheet will calculate the height of a groundwater mound beneath a stormwater infiltration basin. More information can be found in the U.S. Geological Survey Scientific Investigations Report 2010-5102 "Simulation of groundwater mounding beneath hypothetical stormwater infiltration basins".

The user must specify infiltration rate (R), specific yield (Sy), horizontal hydraulic conductivity (Kh), basin dimensions (x, y), duration of infiltration period (t), and the initial thickness of the saturated zone (hi(0), height of the water table if the bottom of the aquifer is the datum). For a square basin the half width equals the half length (x = y). For a rectangular basin, if the user wants the water-table changes perpendicular to the long side, specify x as the short dimension and y as the long dimension. Conversely, if the user wants the values perpendicular to the short side, specify y as the short dimension, x as the long dimension. All distances are from the center of the basin. Users can change the distances from the center of the basin at which water-table aquifer thickness are calculated.
Cells highlighted in yellow are values that can be changed by the user. Cells highlighted in red are output values based on user-specified inputs. The user MUST click the blue "Re-Calculate Now" button each time ANY of the user-specified inputs are changed otherwise necessary iterations to converge on the correct solution will not be done and values shown will be incorrect. Use consistent units for all input values (for example, feet and days)

use consistent units (e.g. feet & days **or** inches & hours)

Input Values		
0.5400	***R***	**Recharge (infiltration) rate (feet/day)**
0.080	**Sy**	**Specific yield, Sy (dimensionless, between 0 and 1)**
5.40	**K**	**Horizontal hydraulic conductivity, Kh (feet/day)***
98.000	**x**	**1/2 length of basin (x direction, in feet)**
20.750	**y**	**1/2 width of basin (y direction, in feet)**
0.374	**t**	**duration of infiltration period (days)**
5.000	**hi(0)**	**initial thickness of saturated zone (feet)**

Conversion Table

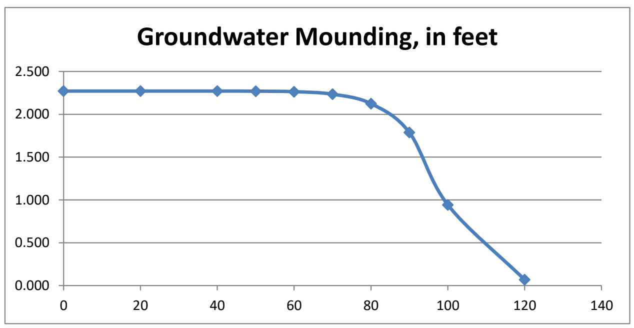
inch/hour	**feet/day**
0.67	1.33
2.00	4.00
hours	**days**
36	1.50

In the report accompanying this spreadsheet (USGS SIR 2010-5102), vertical soil permeability (ft/d) is assumed to be one-tenth horizontal hydraulic conductivity (ft/d).

7.271	**h(max)**	**maximum thickness of saturated zone (beneath center of basin at end of infiltration period)**
2.271	**Δh(max)**	**maximum groundwater mounding (beneath center of basin at end of infiltration period)**

Ground-water Mounding, in feet	**Distance from center of basin in x direction, in feet**
2.271	**0**
2.271	**20**
2.271	**40**
2.270	**50**
2.264	**60**
2.235	**70**
2.125	**80**
1.788	**90**
0.943	**100**
0.069	**120**

Re-Calculate Now



Disclaimer

This spreadsheet solving the Hantush (1967) equation for ground-water mounding beneath an infiltration basin is made available to the general public as a convenience for those wishing to replicate values documented in the USGS Scientific Investigations Report 2010-5102 "Groundwater mounding beneath hypothetical stormwater infiltration basins" or to calculate values based on user-specified site conditions. Any changes made to the spreadsheet (other than values identified as user-specified) after transmission from the USGS could have unintended, undesirable consequences. These consequences could include, but may not be limited to: erroneous output, numerical instabilities, and violations of underlying assumptions that are inherent in results presented in the accompanying USGS published report. The USGS assumes no responsibility for the consequences of any changes made to the spreadsheet. If changes are made to the spreadsheet, the user is responsible for documenting the changes and justifying the results and conclusions.

Large Infiltration System V-2

This spreadsheet will calculate the height of a groundwater mound beneath a stormwater infiltration basin. More information can be found in the U.S. Geological Survey Scientific Investigations Report 2010-5102 "Simulation of groundwater mounding beneath hypothetical stormwater infiltration basins".

The user must specify infiltration rate (R), specific yield (Sy), horizontal hydraulic conductivity (Kh), basin dimensions (x, y), duration of infiltration period (t), and the initial thickness of the saturated zone (hi(0), height of the water table if the bottom of the aquifer is the datum). For a square basin the half width equals the half length (x = y). For a rectangular basin, if the user wants the water-table changes perpendicular to the long side, specify x as the short dimension and y as the long dimension. Conversely, if the user wants the values perpendicular to the short side, specify y as the short dimension, x as the long dimension. All distances are from the center of the basin. Users can change the distances from the center of the basin at which water-table aquifer thickness are calculated.
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use consistent units (e.g. feet & days **or** inches & hours)

Input Values		
0.2014	***R***	**Recharge (infiltration) rate (feet/day)**
0.080	**Sy**	**Specific yield, Sy (dimensionless, between 0 and 1)**
5.40	**K**	**Horizontal hydraulic conductivity, Kh (feet/day)***
98.000	**x**	**1/2 length of basin (x direction, in feet)**
20.750	**y**	**1/2 width of basin (y direction, in feet)**
1.000	**t**	**duration of infiltration period (days)**
5.000	**hi(0)**	**initial thickness of saturated zone (feet)**
6.850	**h(max)**	**maximum thickness of saturated zone (beneath center of basin at end of infiltration period)**
1.850	**Δh(max)**	**maximum groundwater mounding (beneath center of basin at end of infiltration period)**

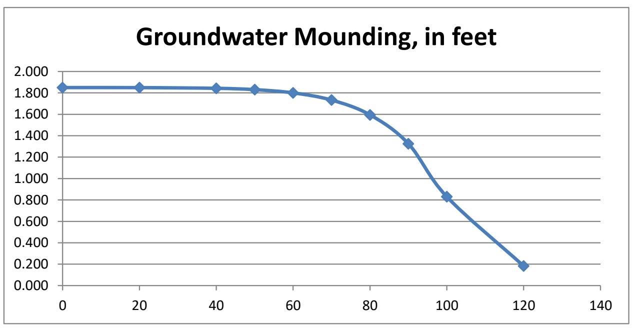
Conversion Table

inch/hour	**feet/day**
0.67	1.33
2.00	4.00
hours	**days**
36	1.50

In the report accompanying this spreadsheet (USGS SIR 2010-5102), vertical soil permeability (ft/d) is assumed to be one-tenth horizontal hydraulic conductivity (ft/d).

Ground-water Mounding, in feet	**Distance from center of basin in x direction, in feet**
1.850	**0**
1.849	**20**
1.843	**40**
1.830	**50**
1.800	**60**
1.733	**70**
1.595	**80**
1.325	**90**
0.830	**100**
0.183	**120**

Re-Calculate Now



Disclaimer

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GZA GeoEnvironmental Inc.

188 Valley St, Providence
Rhode Island 02909

Project Thorndike Place
Arlington, MA

File No. 35410.00

Date: 7/24/2024
Sheet 1 of 1
By: ABU

Estimate steady state flow to a well extracting ground water from a water table aquifer,

$H := 7$	Static head from bottom of aquifer (Ft)
$hw := 5$	Depth of water in a fully penetrating extraction well (Ft)
$k := 5.4$	Hydraulic Conductivity (Ft/Day)
$R := 120$	Radius, or cone of influance (Ft/Day)
$Rw := 51$	Radius of extraction well (Ft)
Qw	Ground water extraction rate (Cubic Ft/Day)

$$Qw := \frac{\pi \cdot k \cdot \left(H^2 - hw^2\right)}{\ln\left(\frac{R}{Rw}\right)}$$

Theim-Dupuit Equation [1]

$Qw = 475.829$ Cubic Ft/Day $\quad Qgpm := Qw \cdot \frac{7.5}{1440} \quad Qgpm = 2.48$ GPM

$r := Rw, 13 .. R$

$$s(r) := -(H - hw) + \frac{Qw \cdot \ln\left(\frac{r}{Rw}\right)}{\pi \cdot k \cdot (H + hw)}$$

1. Ground Water Manual, U.S. Department of the Interior, Revised edition 1981, P.30