*J. Matthew Davis & Associates, LLC*
2 Maple St, Durham NH 03824
(603) 867-9762

To: Conservation Commission, Town of Wayland Massachusetts

Attn: Ms. Linda Hansen
41 Cochituate Road
Wayland, MA 01778
*Delivered electronically, hard copies upon request*

From: J. Matthew Davis, PhD

Date: February 26, 2024

Subject: Peer review of groundwater mounding analysis for the 24 South St project

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At the request of the Town of Wayland Conservation Commission, I have prepared this report summarizing my findings of the peer review of the groundwater mounding analysis for the 24 South St site. I have relied upon the following documents provided to me by the Town.

1. Creative Land and Water Engineering, LLC.
   Letter to Windsor Place LLC – August 26, 2020; Revised November 9, 2020.
2. GeoHydroCylce, Inc.
   Letter to Creative Land and Water Engineering, LLC – July 23, 2020
3. Creative Land and Water Engineering, LLC
   Slug Test and Groundwater Mounding Analysis Report – February 28, 2018; Revised March 1, 2018; Second Revision May 7, 2018
4. Creative Land and Water Engineering, LLC
   Hantush Report, June 10, 2018
5. Creative Land and Water Engineering, LLC
   Hantush Report, August 15, 2018
6. Scott W. Horsley response to NOI, dated January 21, 2021
7. Scott W. Horsely comment letter, dated September 13, 2023

In addition to the documents listed above, I received via email two zip archives of the model files[1] corresponding to the modeling described in the GeoHydroCycle (GHC) report [2].

[1] `Model WW 2 Layer.zip` contains 72 files associated with MODFLOW groundwater mounding analysis for the wastewater infiltration system and `Model SW 2 Layer 2.zip` contains 80 files associated with the MODFLOW mounding analysis for the stormwater system.

**Qualifications**

I hold a M.S. and Ph.D. in Hydrology from the New Mexico Institute of Mining & Technology (New Mexico Tech) and have been a full-time faculty at the University of New Hampshire since 1993. I teach courses on topics including Groundwater Hydrology and Techniques in Environmental Sciences and supervise graduate student theses that involve field investigations and quantitative analysis. As a part time consultant, I have worked for environmental consulting firms, state agencies, municipalities, universities, and law firms providing a wide range of hydrogeologic consulting services. Most pertinent to this review is my work developing MODFLOW models to support permitting applications for water supply wells and wastewater/stormwater infiltration systems, both in New Hampshire and Massachusetts.

**Introduction**

This review focuses on the groundwater mounding analysis using the materials provided by the applicant and their consultants (documents 1-5 above and the model files[2]). Reviews of the letters from Mr. Horsley (documents 6 and 7) focus only on those aspects directly related to the groundwater mounding analysis. Reference to these documents in my review will refer to the numbers provided above[3].

The groundwater mounding analysis conducted by the applicant uses industry standard methods including field investigations (digging test pits, installing monitoring wells, surveying elevations, and conducting slug tests), analysis of slug test data to determine the hydraulic conductivity of the materials, and estimating mounding heights using both quasi-analytical methods (Hantush) and numerical groundwater models (MODFLOW).

The main objective of a groundwater mounding analysis is to assess the expected maximum mound height that would be result from operating the wastewater and stormwater infiltrations areas during seasonal high groundwater conditions. The main elements of this analysis are (1) the estimation of the naturally occurring (pre-development) seasonal high groundwater elevations (ESHGW), (2) calculating a mound height using design infiltration rates and the

[2] On February 21, 2024, I had a brief phone conversation with Mr. Smith of GHC to discuss the delivery of additional modeling files.

[3] CLAWE [1] reports a meeting with the MA DEP regarding the Town's request for a MODFLOW analysis and asserts that the parties agreed to use the existing site data for the MODFLOW analysis. While it is common for MA DEP to work with applicants during the initial stages of a site investigation and to issue a letter approving the workplan for the investigations, I have not received a copy of that letter or the details of what has been agreed to or the conditions of those approvals. For completeness, I reviewed all data and analyses provided to me in the documents above.

hydrogeologic conditions of the site, and (3) assessing the impacts that post-development mounding will have across the site[4].

My review has identified several major issues related to the characterization of the aquifer materials, the calculation of hydraulic conductivity, and the MODFLOW model configuration. Because of the serious deficiencies in the mounding analysis to date, the suitability of the site and the impact of mounding on the stormwater and wastewater infiltration systems and surrounding area cannot yet be determined.

**ESHGW**

The goal of determining the estimated seasonal high groundwater elevations (ESHGW) is to establish a baseline for assessing the impact that mounding from the infiltration areas will have on the infiltration systems and surrounding area during periods of seasonal high groundwater (i.e., Spring).

CLAWE [3] provides the results of the field investigations performed to determine ESHGW, including test pit data and measurements of water levels in monitoring wells. Horsley [7] comments on the use of water levels from a nearby USGS monitoring well.

Test pit data from 8 of the 10 test pits (CLAWE [3]) indicate the presence of seasonal high ground water elevations. These typically consist of observed horizons of redoximorphic features (staining of sands and silts through weathering and oxidation of minerals). CLAWE [3] reports two of the test pits (DTH-4 and DTH-7) as having ESGHW below the bottom of the pit. While the presence of redoximorphic conditions helps to establish the ESHGW, their absence may be due to the lack of weathering and oxidation conditions rather than a deeper seasonal high water table. It is recommended that values from DTH-4 and DTH-7 be referred to as ‘not observed’.

CLAWE [3] also reports data from three monitoring wells observed on four different dates. From these observations, they suggest that the springtime measurements on March 12, 2018 are representative of ESHGW. There is not much discussion on how ESHGW across the site is determined, but in their summary of the mounding analysis (item 3 on page 5), they suggest that use the observation in MW 3 (160.14 ft) is the site-wide value. In the subsequent MODFLOW analysis, GeoHydroCycle (GHC) [2] indicates that the ESHGW used for the wastewater infiltration area is determined from observations in the closest test pit and monitoring wells.

[4] Massachusetts Stormwater Handbook – Volume 3, p.28 “The mounding analysis must also show that the groundwater mound that forms under the recharge system will not break out above the land or water surface of a wetland (e.g., it doesn’t increase the water sheet elevation in a Bordering Vegetated Wetland, Salt Marsh, or Land Under Water within the 72-hour evaluation period).”

These values range from 158.62 to 160.00. The rationale for the values presented in Table 3 of GHC [2] (dated August 15, 2018) are not discussed in the materials provided.

Horsley [6] cites a letter from CLAWE in 2018 and its reference to the USGS monitoring well WKW2 nearby. Horsley [7] refers to the MADEP Stormwater Handbook which defines seasonal high groundwater as representing “the highest groundwater elevation”. Horsley [7] then appears to suggest that “the highest groundwater elevation” is a historical high rather than a seasonal high. The USGS well has since been replaced and the elevations reported appear to be offset from those referenced by CLAWE and Horsley, the matter of the use of the USGS well for estimating seasonal high water at the site needs further evaluation. My recommendation is that if data from a nearby USGS well are used to estimate seasonal high water table at the site, a methodology should be used that considers the range in variations in both on-site observations and those from the USGS well (e.g., Frimpter method[5]), rather than extrapolating individual observations from the USGS observations to the site.

**Hydrogeologic Investigation**

*Site Characterization*

CLAWE [3] uses both soil survey and drilling data to characterize the site as having “very permeable soils” and “very sandy outwash”, respectively. While the Soil Borings provided in CLAWE [3] do support the Soil Survey, as the upper most layers consist of “gravelly loamy sand” and “m[edium] gr[ained] sand”, the materials below the water table are finer grained and characterized in the Soil Logs as “fine m[edium] sand”, “fine silty sand”, and f[ine] sil[ty] sand”. The Soil Logs also report blow counts that are typically performed when collecting split spoon samples through a hollow stem auger. While there is no additional information on the conditions associated with the blow counts, they are often done in accordance with the Standard Penetration Test (SPT) as described in the US Bureau of Reclamation Engineering Geology Field Manual[6] and the reporting of four numbers is consistent with that methodology. Blow counts are the number of hammer blows required to advance a soil sampler over some interval. Of the sequence of four numbers (each representing the number of blows to advance 6 inches), the middle two are added to get the so-called N value. N values greater than 30 indicate a “Dense” sand and greater than 50 a “Very Dense” sand (see footnote 5). The N values for MW1,

[5] Barclay, J.R., and Mullaney, J.R., 2020, Updating data inputs, assessing trends, and evaluating a method to estimate probable high groundwater levels in selected areas of Massachusetts: U.S. Geological Survey Scientific Investigations Report 2020–5036, 45 p., https://doi.org/10.3133/sir20205036.

[6] U.S. Bureau of Reclamation, 1998, Engineering Geology Field Manual, Volume 1, Chapter 22, 2nd Edition. https://www.usbr.gov/tsc/techreferences/mands/geologyfieldmanual.html

MW2, and MW3 are 54, 75, and 49, respectively. The soil sample descriptions and the blow counts below the water table are consistent and indicate a very dense fine silty sand.

The Soil Logs are also used to determine the base elevation of the aquifer materials. CLAWE [3] uses the depth to "refusal" to calculate the bottom of the aquifer materials. While this is reasonable for MW2 and MW3, the Soil Log for MW1 shows that the drilling encountered very dense materials at a depth of 20 feet (5 feet above the bedrock) as 60 blow counts were required to advance the sampler 3 inches. The inability to advance the sampler with the hammer indicates a very dense material that should be characterized as an aquitard rather than part of the aquifer. It appears the remainder of the hole was augered to determine the depth to bedrock. In summary, the thickness of the saturated zone of the aquifer materials is approximately 12 feet thick (Table 1) and should be characterized as dense to very dense fine silty sand.

*Table 1. Summary of aquifer thickness as the difference between the highest measured water levels and the bottom of sand elevation.*

| Well ID | Bottom of well | Ground elev., ft | Bottom of Sand elev., ft | High water level (3/12/2018) | Max Saturated Thickness |
|---|---|---|---|---|---|
| MW 1 | 142.7 | 167.7 | 146.7 | 160.20 | 13.50 |
| MW 2 | 146.2 | 164.2 | 146.2 | 157.04 | 10.84 |
| MW 3 | 148.1 | 163.1 | 148.1 | 160.14 | 12.04 |

*Slug Test Analysis*

Slug tests are used to estimate the hydraulic conductivity of the aquifer materials. Hydraulic conductivity is a critically important parameter that describes the ease with which water will flow through a porous media. Lower conductivity materials will inhibit flow and result in greater mound heights than higher conductivity materials. The slug tests are conducted by imposing a small stress on the aquifer by inserting a solid slug into a well that displaces the water column upward. Water levels are then measured to record the rate at which the aquifer recovers to its original (pre-slug) water level.

Slug tests were conducted on January 10, 2018, in the three monitoring wells. Each monitoring well consists of 2" PVC that has a slotted section open to the aquifer beneath a solid-wall riser to the ground surface. It is important to note that the water table elevations on January 10, 2018, were below the top of the screen interval for all monitoring wells (see Table 2).

*Table 2. Summary of Water Table Elevation relative to screen elevations. Information from the Monitoring Well Profiles and Table 1 of CLAWE [3.] Note that the Water Table Elevation is between the Top and Bottom Elevations of Screen.*

| Well ID | Top Elevation of Screen [ft] | Bottom Elevation of Screen [ft] | Water Table Elevation (ft) on 1/10/2018 |
|---|---|---|---|
| MW1 | 162.7 | 142.9 | 155.85 |
| MW2 | 161.2 | 146.4 | 154.57 |
| MW3 | 158.1 | 148.3 | 156.06 |

The slug test recovery plots presented by CLAWE [3] clearly exhibit double straight line segments, with an initial rapid recovery (up to 5 seconds) followed by a more gradual recovery for the duration of the test. In their analysis of the slug test data, CLAWE [3] erroneously selected the very early time data (up to 5 seconds) for calculating hydraulic conductivity of the aquifer materials. Figure 1 illustrates the double slope behavior of MW2 slug test response data and portion of the curve used by CLAWE [3].

This initial "A-B" slope reflects the redistribution of the perturbation into the annular space between the screen and aquifer and the unsaturated portion of the aquifer, and the response is not representative of the saturated hydraulic conductivity of the aquifer materials[7]. The correct slope for hydraulic conductivity calculation is the second one, the "B-C" slope, which reflects the hydraulic conductivity of the aquifer and extends out to the duration of the test, at approximately 200 seconds. In addition to the wrong slope being used, CLAWE [3] appears to use the first measured value as the initial response (Ho)[8]. Again, this initial reading represents the initial change imposed on the well and sand pack, but not the aquifer. Butler provides a detailed explanation of the correct way to estimate Ho for slug tests in unconfined aquifers where the screened intervals spans across the water table. This double slope behavior of the response and its interpretation is also explained in Fetter[9] (p. 254-255), which CLAWE [3] cites as their source for the methodology.

[7] Butler, J.J., Jr., 1998, The Design, Performance, and Analysis of Slug Tests, Lewis Publishers, 252pp.
[8] A note on the nomenclature, CLAWE [3] uses H1 as the equivalent of Ho
[9] Fetter, C.W., 1994, Applied Hydrogeology, 3rd Edition, MacMillon Publishing, 691 pp.

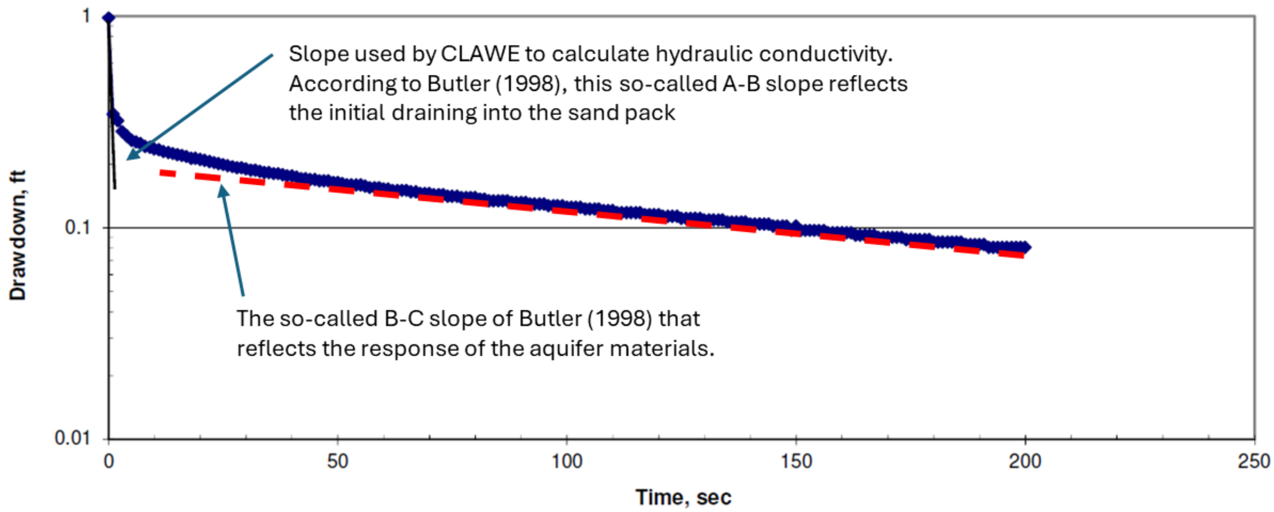


*Figure 1. Illustration of the double slope effect using MW2 from CLAWE [3] as an example.*

It is beyond the scope of this review to recalculate the hydraulic conductivity value for each of the tests, but the difference when using recovery times on the order of hundreds of seconds, rather than the 3 to 5 seconds used by CLAWE [3], will likely result in hydraulic conductivity values that are approximately 50 times less than the ones used for the mounding analysis.

Further analysis of the slug test should also consider the accuracy of the pressure transducers used to collect the response data. CLAWE reports using a 300 ml solid slug to displace water in the monitoring wells and a "level TROLL" to measure the response. ASTM D4044 notes that the rated accuracy of the measuring device should be no less than 1% of the perturbation applied. A 300 ml solid slug inserted into a 2" monitoring well as described in CLAWE [1][10] would produce a maximum water displacement of approximately 0.5ft. However, when accounting for the volume of the sand pack out to the well diameter, the effective water level displacement would be much smaller (see Butler (1998)). In this case, Ho should be closer to 0.1 ft. No additional information is provided on the accuracy specifications of the TROLL. Additional information is needed to assess whether the accuracy of the device used meets ASTM 4044, as asserted by CLAWE [3].

## Calculation of Mound Height

Assessing the impacts of the wastewater infiltration system and the stormwater system on the ground water elevations requires quantitative analysis of the groundwater flow equations. The applicant reports using both the Hantush and MODFLOW methods.

[10] Well diameter is 6" fitted with a 2" PVC for water level measurement and the annulus (radius from 1 to 3 inches) filled with driller sand.

*Hantush method*

The Hantush method is a quasi-analytical solution of the flow equations that relies upon several simplifying assumptions. The results of three sets of Hantush mounding calculations were provided in items [4], [5], and [3]. These are dated August 15, 2018, June 10, 2018 and May 6, 2018, respectively. The Hantush method assumes that the aquifer has a uniform hydraulic conductivity and a uniform thickness through the simulated domain, out to the constant head boundary at the perimeter (in this case 121 ft). The Hantush analyses conducted use different hydraulic conductivity and saturated thickness values, which appear to be based on the location of where the mounding calculation is being performed and do not necessarily reflect the conditions over the area impacted by the infiltration. The Hantush method also does not account for boundary conditions, such as surface water bodies, that may impact mounding. CLAWE [1] reports that it was agreed that a MODFLOW model would be used for the mounding analysis (as MODFLOW does not require the simplifying assumptions of Hantush). As the Hantush mounding analyses provided pre-date the MODFLOW model analysis, the Hantush calculations are not assessed in further detail here.

*MODFLOW method*

The MODFLOW suite of groundwater models provide a great deal of flexibility that enables a detailed assessment of predicted water levels with fewer assumptions than the Hantush method. A MODFLOW model can also allow for the incorporation of field observations (e.g. changes in hydraulic conductivity, aquifer elevations, and thicknesses; observed water levels; and ground surface elevations) directly into the analysis. The sources of water (e.g., infiltration) and sinks (e.g., wetland surface) that affect mounding can be included in the model as boundary conditions.

The goals of the modeling by GeoHydroCycle Inc (GHC) [2] were to assess the cumulative effects of the wastewater discharge to the infiltration areas and percolation from the stormwater system, both under seasonal high conditions.

The hydraulic conductivity values used in the model are those calculated from the slug tests discussed above and need to be corrected before conducting the final mounding analysis. For this reason, this review focuses on the model construction as it relates to the assessment of the groundwater mounding in the vicinity of infiltration areas, potential for breakout of mounded groundwater to the ground surface, and the potential impact on nearby wetlands (see footnote 4 on page 3). This review is based on the GHC report [2] and model files provided by GHC. The GHC model set up uses two separate groundwater models to simulate the mounding associated with wastewater infiltration and stormwater infiltration.

*Multiple Models*

Unlike what is shown in GHC [2] Figure 5, recharge to the leach field and infiltration basin are not included in the same model. Instead, GHC [2] adds the results of each mounding calculation to the ESHGW elevations. It appears that each analysis was done separately and GHC [2] did not consider the combined effect of both wastewater and stormwater systems on the total mounding height as should be done.

*Model Layers*

The configuration of the layers differs between the two models. The stormwater mounding model uses the layer configurations shown in GHC Figure 4B. However, the wastewater mounding model uses a top elevation of Layer 2 of 14.952 ft and the top of Layer 1 of 15.1 feet. In the stormwater model, the cells that are outside of the stormwater recharge area are set to being inactive (i.e., no flow cells). Neither of the model layering configurations consider the impenetrable materials encountered at the bottom of MW1 noted above.

*Wetland Boundary*

The use of the river package (RIV) to simulate the impacts of mounding in this system is not appropriate for two reasons. First, the water levels in the RIV boundary cells are set equal to the initial arbitrary water level in each model. Doing so will ensure that simulated mound heights (difference between simulated mound and initial water level) will be near zero along the boundary, this is an artifact of the model setup and does not reflect the actual conditions. This also results in the erroneous dissipation of mounding in the vicinity of the wetland, regardless of whether the site conditions allow for such flow. This disconnect is illustrated in GHC [2] Figures 3, 6, and 8. Figure 3 suggests that the wetland is not a hydraulic boundary during seasonal high conditions (WP1-WP7)[11], as the water level contours cut across the wetland boundary. Figures 6 and 8, on the other hand, show that the simulated mound heights are significantly impacted by the RIV cells in the model which, due the model configuration, precludes the mound from extending into the wetland. Horsley [7] also points to this concern with the wetland boundary condition. The drain package (DRN) allows for the consideration of mounding within the wetland, without the limitations of the river package, and should be used instead of the river package.

To assess the impacts of mounding, it would also be more appropriate for the groundwater model to include readily available surface elevations[12] as the top of Layer 1. This would enable the

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[11] No information is provided on when the water levels in WP1 through WP7 were collected. It is therefore difficult to confirm their significance in determining the ESHGW elevations at these locations.
[12] https://www.mass.gov/info-details/massgis-data-lidar-terrain-data

MODFLOW boundary condition elevations to reflect actual elevations and would also enable an assessment of potential breakout of the mound to the ground surface.

*Infiltration*

GHC [2] uses the MODFLOW Recharge package (RCH) to simulate the wastewater and stormwater infiltration systems. GHC's approach to modeling the stormwater infiltration basin as an open water body (with a hydraulic conductivity 50,000 ft/day) is not necessary as water is not moving horizontally within the infiltration basin (as may be the case for a large lake[13]). If the desire is to prevent horizontal flow out of the stormwater system in the saturated zone, the Horizontal Flow Barrier (HFB) package[14] should be used for the cells along the outer perimeter of the stormwater infiltration system. By treating the top model layer (Layer 1) as inactive also creates a no flow boundary at the ground surface that is not consistent with the field conditions. In the model files provided, the mounding does not rise to the base of Layer 1 so all of Layer 1 is above the water table and inactive anyway. The recharge values set in Layer 1 are applied to Layer 2 instead[15].

**Summary**

In Summary, my review identified the following concerns regarding the groundwater mounding analysis, as presented in the materials provided to me:

1. Based on the descriptions and blow counts recorded in the Soil Logs, the subsurface materials at the site should be characterized as dense to very dense fine silty sand, with aquitard material in the lowest 5 feet of MW1.
2. The hydraulic conductivity values computed from the slug test results are incorrect. The calculations presented in CLAWE [3] use the incorrect initial response (Ho) and the incorrect slope to compute hydraulic conductivity. The corrected analysis is expected to yield a hydraulic conductivity that is approximately 50 times less than the ones used in the mounding analyses. It is imperative that the hydraulic conductivity values be corrected.
3. Additional information on the specifications of the slug test monitoring equipment is needed to assess whether the existing data meets the recommended accuracy requirements of ASTM D4044, which is the method that the applicant cites as being used.
4. Because the hydraulic conductivity values were calculated incorrectly, the magnitude of the mound heights computed by the Hantush and MODFLOW models are not applicable

[13] GHC cites a regional groundwater model as justification for their approach.
[14] Hsieh, P.A., and J.R. Feckleton, 1993, Documentation of a computer program to simulate horizontal-flow barriers using the U.S. Geological Survey's modular three-dimensional finite-difference ground-water flow model, USGS, Open-File Report, 92-477, https://pubs.usgs.gov/of/1992/0477/report.pdf
[15] The MODFLOW NRCHOP parameter set to 3, which applies the recharge to the uppermost active layer.

to site conditions. Mounding analysis will need to be redone once the hydraulic conductivity values are corrected. Reducing hydraulic conductivity values by a factor of 50 will result in much higher mound heights, estimated to approach 7 feet in the wastewater infiltration system[16]. For comparison, the currently modeled maximum mound height in the wastewater infiltration system is 0.40 ft. All mounding analyses need to be redone using correct hydraulic conductivity values.

5. The MODFLOW model has several key deficiencies that limit its ability to compute mounding that is representative of the site conditions. In addition to using incorrect hydraulic conductivity values provide by CLAWE [3], the model configuration has the following issues:
    a. A single MODFLOW model should be used for both wastewater and stormwater infiltration systems.
    b. Actual surface elevations should be used for the top of Layer 1.
    c. The wetland boundary should be represented by the MODFLOW drain package with the drain elevations set to the wetland surface elevation, rather than the river package set to an arbitrary value.
    d. If it is expected that the stormwater chamber will extend below the mounded water table, the MODFLOW horizontal flow barrier (HFB) should be used, rather than setting the entire model layer as inactive cells.

[16] The model files provided by GHC were loaded into Groundwater Vistas (version 8.30 Build 215) and run with MODFLOW 96 (as was used by GHC).