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MEMORANDUM

To:	Kimberly Groff, Southeast New England Program
From:	Neal Price
Date:	February 16, 2024
Re:	Model Simulations Summary Technical Memorandum – Sharon Great Cedar Swamp
cc:	Josh Philibert, Town of Sharon; Eric Ford, Division of Ecological Restoration

The Horsley Witten Group, Inc. (HW) is pleased to submit this memorandum summarizing groundwater modeling conducted this past summer and autumn for the area in and around the Great Cedar Swamp (GCS) in Sharon, Massachusetts (the Site). Modeling was conducted to evaluate five potential control structure elevations for the existing drainage ditch. This work builds upon the conceptual MODFLOW groundwater model for the area developed during a previous phase of this project. MODFLOW simulates aquifers as a three-dimensional grid of interconnected cells. Properties (e.g. hydraulic conductivity, and recharge) are prescribed for each cell such that the model can simultaneously solve groundwater flow equations for each cell to its adjacent cells, and so on throughout the grid. Ultimately, simultaneous solutions of the thousands of interconnected cell equations produce predicted water levels for each cell based on the various input parameters so that a groundwater contour map can be produced and an understanding gained of how groundwater moves through the aquifer. Changing the prescribed parameters of cells allows the modeler to simulate scenarios of different groundwater conditions,

The field work that supported the development of this model, which included manual water level measurements, manual streamflow measurements, surveying, and the use of water level loggers, was summarized in a previous technical memorandum.

Background

The GCS consists of 250± acres of land within the Town of Sharon in Norfolk County, Massachusetts. The site is owned and managed by the Town and consists of a large wetland complex that includes an Atlantic White Cedar (*Chamaecyparis thyoides*) swamp – a globally rare community type. The GCS is an important natural resource to the Town due to the important open space and habitat protection services it offers. In addition, because the GCS is located at relatively high elevation in the local aquifer system and is undeveloped, it provides clean groundwater recharge that contributes to most of the Town's public water supply wells. The GCS also feeds Lake Massapoag, a popular recreational resource.

The GCS is currently impaired by a drainage ditch that lies along its western edge. This ditch was created during the construction of an adjacent residential subdivision (“The Heights”). The ditch drained groundwater from the near surface, lowering groundwater levels and increasing separation for the construction of septic systems, basements, catch basins, and other subsurface infrastructure. The ditch also had the effect of draining water and reducing groundwater levels within the GCS. The ditch has lowered groundwater levels beneath a large portion of the GCS sufficiently to cause die-off of the wetland vegetation and replacement with more upland facultative species. The decline in groundwater levels has led to a noticeable amount of soil subsidence within the GCS.

The value of the GCS and the detrimental impacts of the drainage ditch have become more recognized and understood since the Heights were originally developed. In an early attempt by the Town to mitigate these impacts, a small baffle structure of rip rap stone was constructed in the ditch approximately 200-feet upstream of the Wolomolopoag Street culvert. The structure, composed of a riprap base atop the streambed and additional riprap reinforcing the streambank, impounded a small amount of water (approximately 1.5 feet above the streambed) and caused minimal increase to groundwater levels in the GCS surrounding the ditch.

The modeling effort described in this report was undertaken to assess the impacts of proposed a flow control structure designed to impound water within the GCS ditch to a higher elevation than the existing rip rap baffles. The hypothetical flow control structure assessed in this report would be installed in a similar position in the ditch to the existing baffle structures. The flow control structure would retain water behind it, reducing overall discharge downstream through the Wolomolopoag Street culvert. The retained water, impounded behind the structure, would increase the stream stage in the ditch to the elevation of the flow control structure. As the stream stage increases, the potential for water to enter the stream from the surrounding aquifer (e.g. the potential to drain) decreases correspondingly. Five scenarios, representing five different impoundment elevations for the flow control structure, were assessed in this study. Model results were assessed to balance the competing interests of increasing water levels in the GCS while avoiding negative impacts to subsurface infrastructure in the Heights neighborhood.

Data Sources Used in Model Development

Several data sources are needed to produce a groundwater model. In this effort, modeling combined data sources from publicly available resources, previously written reports, and data collected on site in 2010 and 2023 by the project team. The following data sources were primarily utilized to determine physical characteristics of the area including surficial geologic materials and ground surface elevations.

- Surficial geology was determined based on the MassGIS Surficial Geology (24K) layer.
- Surface elevation data was determined based on the 2021 Central Eastern MA LiDAR survey.
- The location of the drainage ditch, Canoe River, and Beaver Brook were based on the MassGIS 25K hyrdrography dataset. Elevations for these surface water features were

determined based on the LiDAR elevation for each model cell along each of those watercourses.

- A USGS index well (MA NNW27R) was incorporated to understand the temporal context of the regional hydrology.
- Numerous borings in the GCS and surrounding area were compiled by IEP Inc for an Aquifer Protection Study in 1987, providing local information about subsurface conditions.

The results of multiple fieldwork efforts provided further detail about the GCS and the drainage ditch, as well as calibration targets for the model. Two separate water level measurement events occurred throughout the GCS in spring and summer of 2010, producing interpolated water table surfaces for the entire GCS for each sampling event, as well as specific elevations for water table elevation at monitoring points throughout the area. These water table maps served as the basis for calibration, as discussed later in this report. In 2011, surveyors from Horsley Witten Group produced a transect profile of the drainage ditch elevation as well as cross sections of the stream channel at two locations.

In 2023, Horsley Witten, in partnership with DER and the Town of Sharon, undertook additional field work on the site installing continuous water level loggers in monitoring wells and stream gauging sites, locating infrastructure features, and further characterizing the GCS ditch in the vicinity of the Wolomolopoag Street culvert. Locations and elevations of features were recorded using a real time kinematic global positioning system (RTK GPS) during the 2023 monitoring effort. The 2023 monitoring effort is described in detail in a Field Data Technical Memo delivered to DER on June 30, 2023.

MODFLOW Groundwater Model Development

Model development was performed using Groundwater Vistas version 8 (Environmental Systems, Inc.) and MODFLOW-2005 (United States Geological Survey). MODFLOW-2005 is a three-dimensional finite-difference groundwater model. Properties and boundary conditions are assigned to cells within the finite-difference grid using the Groundwater Vistas interface. The MODFLOW-2005 model then performs calculations based on this grid, yielding a numerical solution (model result) representing groundwater conditions which satisfy the conditions set out in the model. Following initial development of the model, parameters were adjusted through a manual calibration process to yield results which reasonably reflect observed groundwater conditions in the project locus.

<u>Model Domain</u>

The model domain was chosen to include significant features of the four surface water watersheds which surround the GCS. To the east, the model domain extends into Massapoag Lake. To the north, the model includes approximately 9,300 linear feet of Beaver Brook, including a reach of the Brook which runs approximately east-west. The hydrogeologic divide created by this reach was included as the approximate northern extent of the model. The western extent of the model includes the Billings Brook tributaries to the Cedar Swamp Brooks, which is the ultimate drainage of the ditch within the GCS. The southern extent of the model domain includes the Canoe River headwaters south of the GCS. Approximately 9,000 linear feet of the Canoe River's highest reaches were included to characterize this drainage area's influence on hydrology of the GCS. The model domain is indicated in Figure 1.

Boundary Conditions

Boundary conditions included in the model represent stream cells (for the GCS ditch, Beaver Brook, and Canoe River), constant head cells (for major surface water bodies), and no-flow cells at the outer edge of the model domain. The boundary conditions in the model are shown in Figure 1.

Constant head boundaries are only defined by a single parameter (head), which must be met in the solution to the model. Constant head boundaries selected for this model represent major surface waterbodies within the model domain. Heads of these waterbodies were determined based on LiDAR derived water body surface elevations. The LiDAR elevation of Massapoag Lake was assessed against field measured values to determine that the elevations used for constant head boundaries represent long term average conditions. The nearest modeled constant head boundaries to the Heights neighborhood and the GCS are Wolomolopoag Pond, approximately 3,000 feet to the west, and Lake Massapoag, approximately 2,000 feet to the east.

Stream cell boundaries allow for water to enter or exit the aquifer system via stream cells. The parameters defining a stream boundary include the bottom elevation of the stream, the stage of the stream, and components of streambed conductance. The bottom elevation of streams in the model was determined based on high resolution LiDAR imagery of the model domain. For the GCS drainage ditch, LiDAR elevations were validated against a stream profile survey performed by HW in 2011 and survey points located with RTK GPS in 2023. Stage throughout the ditch was estimated based on average stage data collected during the field monitoring task of this project, interpolated between gauging sites. Conductance of the stream was adjusted to calibrate model mass balance results with field-estimated baseflow discharge volumes for the drainage ditch.

Physical Characteristics, Model Properties

Surficial geology of the GCS is swamp deposits overlaying coarse glacially stratified deposits. The depth of swamp deposits in the GCS were based on observations of swamp sediment depth observable in the drainage ditch as well as an organic sediment depth transect conducted along the eastern edge of the railroad bed within the GCS, included in the Sharon GCS Progress Report, June 30, 2012 (Fletcher et al, 2012). Combined, these data points suggest the swamp deposits extend approximately 10 feet below ground surface throughout the swamp. Outside of the GCS and nearby swamp areas, the predominant surficial geology is coarse glacially stratified deposits. Till is present to the south and east of the GCS in the vicinity of Barefoot and Dudley Hills. It is assumed that glacial till underlays the entire model domain, including in areas where it is not present on the surface. Areas of shallow bedrock were identified from surface geology maps. The depths to bedrock in areas of till and glacial stratified deposits were interpolated from boring information produced during the Aquifer Protection Study conducted by IEP in 1987. “Refusal” in these boring logs was assumed to represent a low-conductivity fractured bedrock underlayment.

Based on the information reviewed, the model was vertically separated into 5 layers. The lowest layer represents low conductivity fractured bedrock which is assumed to underlay the entire model domain. This layer has a flat bottom at an elevation of 100 feet. The top of this layer and all other layers were assigned relative to surface elevations. The top two layers are each 10 feet thick. In the vicinity of the GCS, the top layer represents swamp deposits. The third layer is 20 feet thick. The fourth layer is 40 feet thick. The lowest layer varies in thickness, with a top elevation 80 feet below the ground surface and constant bottom elevation of 100 feet. Surface elevation contours and top layer conductivity and recharge properties are shown in Figure 2.

Calibration

Development of the baseline model sought to represent long-term average conditions in the GCS. Calibration objectives included head values at monitoring well locations and baseflow contributions from the aquifer to the ditch. The primary means of adjusting calibration of the model involved the adjustment of the lateral and vertical conductivity parameters for the various aquifer materials in the model, as well as adjusting recharge values throughout the model. Aquifer losses to the drainage ditch were calibrated by adjusting the conductance terms of the streambed. Combined, aquifer material properties and streambed conductance properties were calibrated to match head targets for select target points throughout and surrounding the GCS as well as streamflow volumes. Calibration information, including the baseline model water table contours, is indicated in Figure 3.

Head Calibration

One of the primary outputs from a numerical groundwater model is hydrologic head simulated for each cell in the model domain. Head is the hydrostatic pressure within the aquifer, which can be measured as the water elevation measured in a monitoring well. For unconfined aquifers such as the GCS, the hydraulic head measured in a well with a screened interval below the water table will be approximately equal to the elevation of the water table at that location. The modeling team assessed previous groundwater measurements taken at the GCS in 2010, data from the 2023 monitoring effort, and the long-term trends at an index well (MA NNW27R) to determine long-term average groundwater conditions at the project site.

Two rounds of water level measurement were performed in 2010 – one on April 7 and another on August 10. During each event, depth to water was measured at nearly every well in the area yielding specific water elevation values as well as an interpolated water table contour map of the area. At the time of the April 7, 2010 gauging, water levels at the index well were 1.15 feet higher than the long-term average condition. During the August 10, 2010, gauging effort, water levels at the index well were 1.24 feet lower than the long-term average water level. Based on this relationship, the modeling team determined that the average of the water levels observed during these two monitoring events would be a sufficiently accurate approximation of long-term average groundwater levels in the GCS. Monitoring points sampled during these two events were selected to be calibration targets based on spatial variability throughout the area of interest. Water level measurements at those target locations are summarized in Table 1 below.

Figure 3 shows the location of these calibration targets and the residual differences between model-calculated and target heads throughout the site. The root-mean-squared error for the model targets was computed to be 2.46 feet and the range of target heads was 28.07 feet. Residuals are generally lower in the vicinity of the GCS, and higher at targets further from the GCS. While there is no common standard regarding the allowable amount of error in a groundwater model, it is a common practice to compare the RMS error of residual values to the range of target heads as a percentage to assess model accuracy. By this metric, the calibrated model reflects an RMS error of 8.8%, which is within the commonly accepted 10% standard for this metric.

Table 1: GCS 2020 Groundwater Monitoring Results

			Monitoring Events		
	Northing	Easting	4/7/2010	8/10/2010	Average of 2010 monitoring values
HARDING ST	2864160.8	740572.6	253.61	251.65	252.63
MOHAWK ST	2861280.6	740062.19	258.46	254.76	256.61
S MAIN AND HAMPSHIRE	2864682.5	738043.09	236.16	232.82	234.49
A8E	2859848.3	737400.73	256.92	255	255.96
S Main and sunset	2863810.1	736333.02	256.5	252	254.25
49 Garden St	2864565.4	739149.86	249.19	244.67	246.93
B2W	2862568.7	737018.11	256.22	254.16	255.19
A1E	2860315.9	736371.41	255.28	251.01	253.145
A2E	2860265.6	736503.67	256.11	251.67	253.89
A1W	2860372.1	736246.99	254.29	250.69	252.49
Essex	2863415.1	738047.48	259.19	254.28	256.735
Sunset	2863393.9	736735.95	258.12	254.26	256.19
MA NNW27R			157.7	155.31	156.505
		Calculated Long Term Average			156.55

Ditch Baseflow Calibration

Streamflow was not measured during the 2010 groundwater monitoring events which formed the basis for head calibration. Streamflow was measured four times at two monitoring points during the 2023 monitoring period. Streamflow measurements at SF1, the further-downstream of the monitoring points, are summarized in Table 2 below.

Table 2: Streamflow measurement events (2023)

Date	**SF1 Flow (cfs)**	**SF1 Flow (cfd)**
1/31/23	4.08	352,512
2/14/23	1.34	115,776
3/16/23	7.53	650,592
4/11/23	0.93	80,352
Average	3.47	299,808

Stream stage was continuously measured using Van Essen Diver pressure transducers which record water column height above the diver at regular intervals. Hydrographs of stream stage were analyzed to relate streamflow measurements to general hydrologic condition in order to assess the baseflow contribution of groundwater into the stream. Due to the frequency of precipitation events during the monitoring period, stream stage did not stabilize following precipitation events before the next precipitation event began. Falling leg hydrograph slopes remained in steep decline until the next rising leg began. Only one period of relatively stable, uninterrupted streamflow was observed between February 16 and February 22, 2023. Between February 22 and the end of monitoring on April 11, 2023, streamflow values did not stabilize to a steady baseflow condition.

As discussed in the Field Data Technical Memo, the 2023 monitoring period occurred in wetter-than-average regional hydrologic conditions. Groundwater elevations in USGS MA-NNW27R did not fall below 74th percentile values during the monitoring period, and the average value was the 87th percentile. December and January (preceding the monitoring period) and March (during the monitoring period) all exceeded long term average precipitation volumes. Given the regional hydrologic conditions during which monitoring took place, coupled with the lack of hydrograph stabilization, the lowest streamflow measurement on April 11, 2023 was interpreted to most closely resemble a long-term-average baseflow condition.

Streams in the model were represented using the Streamflow Routing package (STR). Streams are primarily characterized in the model based on their bottom elevation, stage, and the conductance of the streambed. Stream bottom elevations were determined based on minimum LiDAR elevations within specific stream cells, adjusted as appropriate based on elevation data collected during the 2010 and 2023 surveys. Stream stage was estimated based on the average depth of water in the ditch during the monitoring period, added above the stream bottom elevation. Conductance refers to the ability of water to pass through the streambed material between the stream channel and the underlying aquifer. The drainage ditch is cut into the GCS providing an almost direct connection to the surrounding material. As such, stream cells were assigned a streambed thickness of 1 foot and a hydraulic conductivity of 75 feet per day to represent a condition where the streambed offers this direct connection with the surrounding material.

Stage, bottom, and conductance allow the model to calculate the amount of water entering or exiting the aquifer in each stream cell. The potential of the stream to gain or lose water is determined by comparing the stream stage with the aquifer head at each cell. This head-stage potential is tempered in the model by the conductance of the streambed, however due to the high conductance of ditch streambed materials reflected in the model this resistance is minimal. The high conductance afforded to stream cells in the model, representing the direct connection of the stream to the surrounding material, means that the elevation of the stream bed and the stage of the stream are the key factors for modeling stream dynamics in this case. Mass balance results for the drainage ditch upstream of Wolomolopoag Street in the baseline model yields a net stream gain of 77,614 CFD. This value is 97% of that of the April 11th streamflow measurement and was determined by the modeling team to adequately represent approximate baseflow conditions for the system.

Subsurface Infrastructure Constraints

The drainage ditch within the GCS was originally built to lower groundwater elevations within the Heights neighborhood. Drainage was necessary to provide sufficient clearance for residential infrastructure within the neighborhood (such as stormwater drains and conveyances, septic systems, and residential basements) from groundwater. Even with the ditch draining the GCS, separation from seasonal high groundwater is low in this neighborhood. Horsley Witten Group reviewed septic installation reports provided by the Town of Sharon and surveyed stormwater infrastructure on Sunset Drive and Lee Road to understand the limitation on potential groundwater level increases which this infrastructure imposes.

Septic system engineering plans for 10 residential properties in the Heights neighborhood were provided by the Town and reviewed by HW. During 2023 field work, stormwater structures at the end of Sunset Road and the intersection of Essex and Lee Road were surveyed. Data from these sources is shown in Figure 4. Septic system elevation data is limited in its application due to a lack of information relating elevations on the plan to an established vertical datum. Four of the septic plans reviewed did have an elevation benchmark associated and the plans state that elevations approximately refer to the USGS NGVD datum (NGVD29). LiDAR ground surface elevations and RTK-measured points located during 2023 field work are vertically referenced to the NAVD88 datum. The difference between NAVD88 and NGVD29 orthometric elevations vary spatially. In the vicinity of the GCS, NGVD29 elevations of 0.76 feet higher than the same elevation measured in the NAVD88 datum.

The remaining plans do not mention any datum information. The range of elevations included in the plans without a specified vertical datum are within the range of actual ground surface elevations in the Heights, suggesting that the septic system designers did not use a made-up “reference” elevation (e.g. 100 feet), but rather did attempt to utilize elevations relative to some vertical datum despite not specifying which.

The differences between the NGVD29, NAVD88, or approximate-assumed datums used in reviewed septic plans limits their direct ability to be compared to other data sets in the project. Additionally, the imprecise nature of a groundwater model and the residual differences which remain between calibration targets and modeled heads further complicate the pursuit of direct elevation-to-elevation assessment of modeled scenario impacts. As such, rather than attempting to compare specific septic system bottom elevations to the modeled groundwater elevation at that location, the change in groundwater elevation under proposed conditions was compared to the baseline conditions model results in order to assess the risk of impact on septic elevations.

Six of the septic plans reviewed included information regarding the elevation adjusted elevation of groundwater at that location based on observations during the septic system design process. The septic systems located at 30 Clark Court and 15 Essex Road had the least separation from groundwater, in addition to being the closest systems reviewed to the GCS ditch. Groundwater at 15 Essex Road was noted at a depth 6.72 feet below the design leach field invert, and the adjusted groundwater elevation was just 4.39 feet below the leach field. The percolation rate at 15 Essex Road was reported as 2 minutes per inch, which qualifies this location for the 4-foot vertical separation requirement under Massachusetts Title V Septic System Requirements. As such, at this most-sensitive receptor, an increase in groundwater elevations by as little as 0.39 feet would violate the septic system requirements as defined in Title V.

	Key Elevations				Datum			
Address	Basement	Leach Field	High Ground Water	Ground Water		Adjusted Groundwater Separation	Groundwater separation	Best GW Data
15 Essex Road	263.38	265.69	261.3	258.9667	Approximate NGVD	**4.39**	6.723333333	Adjusted
30 Clarke Court	256.0*	263.35	No TP	257.8	No datum specified		**5.55**	Groundwater Elv
22 Norfolk Place	258.27	260.1	255.1	253	Approximate NGVD	5	7.1	Adjusted
19 Middlesex Road	264.45	266.19	<259.6	<258.2	Approximate NGVD	6.59	7.99	Adjusted
21 Norfolk Place	261.31	262.87	<257.4	<254.4	Approximate NGVD	5.47	8.47	Adjusted
9 Middlesex Road	257.43*	263.06		255.4	No datum specified		7.66	Groundwater Elv
Systems without test pit information								
22 Lee Road	258.03	260.81			No datum specified	No groundwater data		
24 Suffolk Road	263.63	264.75			Elevation assumed	No groundwater data		
30 Sunset Drive	257.3	258.09			No datum specified	No groundwater data		
4 Lee Road		260.89			No datum specified	No groundwater data		
*Based on reported top of foundation elevation, minus 10 feet								
All elevations are approximate								

Table 3: Septic system key elevations and data limitations based on plans reviewed.

Flow Control Structures Evaluations

The drainage ditch in MODFLOW is represented using the STR (Streamflow Routing) package. This package takes physical characteristics of the stream and calculates the interactions between the stream and the aquifer based on those characteristics. As discussed above, key parameters which define this relationship are the stage of the stream and the conductance of the streambed. If the stage of the stream is higher than the head of the aquifer, then water in the stream has the potential to flow from the stream into the aquifer. Inversely, if the head in the aquifer exceeds the stage of the stream, then water from the aquifer has the potential to flow into the stream. When water enters the aquifer the condition of the stream is called a “losing stream”. When water enters the stream from the aquifer, the stream is considered a “gaining stream”. The ditch in the GCS is a gaining stream throughout the GCS.

Flow control structures will affect the river-aquifer interface by retaining runoff and normal groundwater inflows to the drainage ditch upstream of the flow control structure. In so doing, the flow control structure increases water levels in the stream, increasing its stage. The water retained behind the flow control structure decreases the potential of the stream to drain water from the aquifer, either decreasing the amount that the stream gains or, if the increase causes the stream stage to exceed the local head of the aquifer, causing the stream to contribute water to the aquifer.

The goal of this modeling effort is to assess whether additional water entering the aquifer as a result of a flow control structure in the ditch will impact residential basements, septic systems, and stormwater structures in the Heights neighborhood. Various flow control structures elevations were represented in the model. For each flow control structure, the stage of stream cells upstream of the structure were adjusted to match the top elevation of the structure, to the point upstream where baseline stream stages exceeded this elevation. The steady-state model solution was calculated, and the resulting water table was compared to the baseline water table elevation to indicate the magnitude and extent of change resultant of each proposed scenario. Results are reported in terms of this difference (i.e., “mounding”) to demonstrate the lateral extent of water table increases under various proposed scenarios.

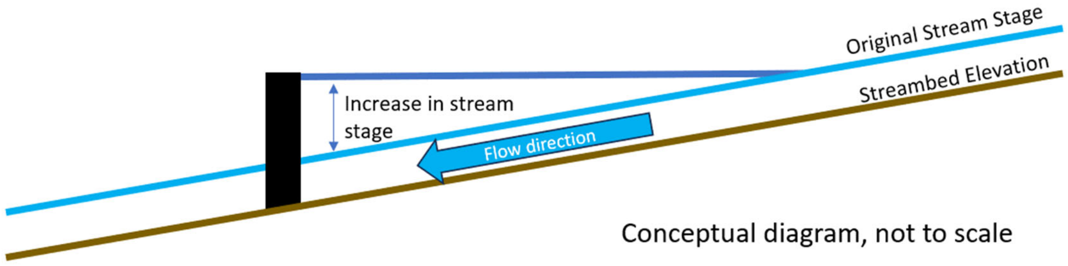

Figure 5: Conceptual diagram of the influence of a flow control structure on stream stage.

Flow control structure scenarios are constrained by the cross-sectional stream channel profile in the vicinity of the target location of the structure. Cross-sectional profiles in the vicinity of the existing riffle structures were surveyed by HW in 2011. At the Wolomolopoag Street culvert, the stream channel was 6.1 feet below the bank, with the banks approximately 23 feet apart. Approximately 1,100 feet upstream, a second cross-sectional profile characterized the ditch with the channel 8 feet below the lowest bank and the banks approximately 27 feet apart. Two existing rip rap baffles were surveyed using RTK GPS during field work efforts in spring of 2023. These two existing structures are approximately 10 feet apart, with the upstream baffle approximately 225 feet upstream of the Wolomolopoag street culvert. The upstream baffle had a top elevation of 251.0 feet. The tops of bank adjacent to this baffle were 257.45 to the southeast and 258.34 to the northwest. The distance bank to bank at this location is approximately 37 feet. The top of this upstream baffle is approximately 1-foot higher than the channel elevation immediate upstream of the baffle.

The riprap baffle structure was assumed to be the prospective location of a proposed flow control structure for modeling purposes. The baffle, located near the downstream extent of the drainage ditch within the GCS, would allow for the maximum amount of water to be retained in the ditch channel at the location furthest away from the infrastructure constraints in the Heights. Stream stage upstream of the baffle in the baseline model was assumed to be equal to the top elevation of the baffle, remaining at this elevation upstream to the point that stream stages, estimated based on stream stage data collected during the monitoring period, exceeded this elevation. As such, the baseline scenario modeled includes the existing baffle. Flow control structure scenarios include additional stream stage above this existing baseline. The theoretical maximum hydraulic retention height for a flow control structure built above this baffle would therefore be limited to 6.4 feet, which would retain water up to the height of the banks of the ditch. Realistically, a flow control structure would not be built to impound to this maximum amount of water. Flow control structures were modeled in 1-foot increments above the existing baffle structure to a maximum height of an additional 5-feet of water impounded.

The slope of the stream channel determines how far upstream water could be impounded by a 5-foot-tall flow control structure above the existing baffle. Given the existing baffle top elevation of 251 feet, a flow control structure of 5 additional feet would retain water to an elevation of approximately 256 feet. At this elevation, stream stages would increase above typical levels approximately as far upstream as Lee Road. The increase would be less than 1-foot further upstream than Sunset Drive. Lower elevation flow control structures were assessed at 1-foot increments to balance the objectives of maximizing resaturation of the GCS while minimizing impacts to neighboring residents.

Results

For each modeled flow control structure scenario, the resultant water table was compared to the baseline scenario and the difference is reported in Figures 6a-e. Subsurface infrastructure in the Heights neighborhood, such as septic systems and stormwater drainage infrastructure, inherently constrains any effort to mitigate the detrimental impacts of the drainage ditch on the GCS. As shown in figure 6c, a flow control structure raising stream stages to 3-feet above the current baffle structure (to an elevation of 254 feet) would increase long-term average groundwater elevations in the vicinity of 15 Essex Road by approximately 0.3 feet, which is the maximum amount of groundwater elevation increase that could occur without impacting the Title V compliance of the system as designed.

The primary factor which determines the lateral extent of groundwater rise under these scenarios is the distance upstream from the flow control structure to which water is impounded above the baseline stream stage. The highest bottom elevation of the ditch is only 3 feet higher than the top of the existing riffle structure, meaning that a flow control structure which impounds 4 feet of water would cause increased water elevations beyond Sunset Drive, and a 5-foot structure would increase water elevations throughout the entire ditch. The physical proximity of the ditch to the neighborhood means that even a small increase in water elevation could potentially cause negative impacts.

The representation of proposed condition scenarios in the model reflect steady state solutions where the stage of the stream is consistently maintained equal to the proposed flow control structure top elevation until groundwater levels throughout the system form an equilibrium with that elevation. In reality, baseflow and surface runoff contributions to the ditch may not provide enough input to maintain this impoundment consistently and the ditch may not retain water to the control elevation of the structure at all times, resulting in less groundwater elevation increase than that reflected in model results. In this way, the results of the model are inherently conservative.

Given the above considerations, it is recommend that a height-adjustable flow control structure capable of holding back water up to a maximum of 4 feet above existing conditions (to approximately 255 feet NAVD88) should be the largest considered for further evaluations. Under typical operation, such a structure would likely be set to retain an elevation of 3 feet of water above the existing riprap baffle structure elevation (to approximately 254 feet NAVD88). Building the structure with another foot of excess capacity would provide managers with the flexibility to temporarily retain additional water to compensate for periods of low streamflow and depressed groundwater elevations. And of course, the structure should be capable of retaining water at levels less than 3 feet above existing conditions such that adaptive management of the structure could be practiced based on results observed for various settings.

Such a structure will significantly increase water table elevations throughout a large area of the GCS while posing minimal risk of negative impact to subsurface infrastructure present in the Heights neighborhood.

Next Steps for Field Data Collection, Modeling, and Other Analyses

Next steps for the project should include preliminary design of a structure similar to the one described above, permitting, and public outreach to assess support from abutters and other affected parties. Preliminary design should include additional survey and research regarding other potentially low-lying infrastructure such as stormwater conduits and septic systems in the vicinity of Wolomolopoag Street and neighborhoods off Chase Drive, which were not assessed during this current effort.

Should a flow control structure be installed, an active monitoring program should be implemented to provide early alert to any potential negative impacts to sensitive receptors such as septic systems. Such a program would likely involve regular monitoring of water levels in wells between the ditch and the Heights to observe the changes in groundwater elevation in this area. Monitoring of impoundment depth in the ditch itself would aid in understanding the relationship between impounded water and surrounding groundwater elevations.

Modeling Limitations

Great care was taken to develop the model described in this memorandum in a manner to address the objectives of the modeling effort. Available data from numerous sources was included to accurately reflect the physical characteristics of the area. Field-measured water table values, adjusted based on regional temporal context, served as the baseline to calibrate the model. Conceptual representations of proposed conditions were carefully considered by the modeling team to adequately represent the potential impacts of those conditions. Despite these best efforts, no model can reflect the real world with complete accuracy.

As with any modeling process, additional efforts could be made to yield a more robust result. Additional field research could be undertaken to better characterize key parameters of the model. Aquifer testing could yield more accurate hydraulic conductivity parameters for key materials in the area, such as the swamp deposits which comprise the GCS or the deposits which underlie the Heights. Data could be collected on local aquifer recharge rates throughout these areas as well. A sensitivity analysis, where model parameters are systematically adjusted through a range of possible values, could also be performed to understand the potential range of error involved in the model.

The modeling effort described in this memorandum represented a steady-state condition, without regard to seasonal variability or the fluctuation in water levels impounded by a flow control structure. Modeling included no analysis of meteorological patterns, runoff patterns, or streamflow hydraulic properties which might cause seasonal variation in streamflow.

Despite these limitations, the modeling discussed here effectively demonstrates the anticipated aquifer responses from simulated flow control structures relative to existing conditions and each other.

While not necessary to advance potential design and permitting of a Town-selected flow control structure, further modeling efforts could include transient modeling, where model parameters vary through time, to better characterize dynamics of the system. Transient modeling may provide further insight into system dynamics such as the rate at which groundwater levels will rise after water is impounded behind a flow control structure and the rate at which groundwater levels will fall when the flow control structure elevation is lowered. Additionally, transient simulations could further develop understanding of the impacts of varying impoundment depths behind the structure due to fluctuations in surface runoff and baseflow to the drainage ditch.

Attached Figures:

Figure 1: Model domain and context; model boundary conditions
Figure 2: Model top layer physical characteristics including conductivity zones, recharge zones, and elevation contours.
Figure 3: Model calibration result targets
Figure 4: Surrounding infrastructure points with the Heights neighborhood
Figure 5: Conceptual diagram of flow-control structure modeling approach (in text)
Figure 6a-e: Mounding contour results from scenarios representing 1-foot (6a), 2-foot (6b), 3-foot (6c), 4-foot (6d), and 5-foot (6e) flow control structures above the existing upstream rip rap baffle.