Beaver Lake

Groundwater Metadata Analysis

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Clear, cool, spring water is the primary source of water for Beaver Lake. To a great degree the beauty of Beaver Lake is based on this unique water source. As water moves through the ground it is filtered and cooled resulting in clean, clear water flowing out of nearshore and lake-bottom springs. In order to keep these springs flowing it is critical to ensure that the source of this ground water is not depleted by increasing demand from a growing population. High capacity wells have the potential of drawing down the level of groundwater and potentially reducing the flow of water into the lake through its many springs. The movement of groundwater near Beaver Lake has been extensively studied (SEWRPC 2014, Feinstein et al. 2010 & Carman 1988) and recommendations have been made to guard against negative impacts to groundwater as the area develops. This paper provides an overview of this research and suggests actions that could be taken to encourage residents and municipal agencies to follow through on the recommended safeguards.

Groundwater in the area of Beaver Lake is found in two major aquifers. Groundwater that feeds Beaver Lake comes from water that is slowly flowing through the rubble dropped in the area by the last glacier. This water and the material it flows through is called the shallow aquifer. This aquifer has a maximum thickness ranging from 100 to 200 feet in the vicinity of Chenequa Village. The movement of water through the sand and gravel of the shallow aquifer is generally in a westerly to southwesterly direction (Figure 1). Below the shallow aquifer is another aquifer where the water moves more slowly through sandstone. This deep aquifer is separated from the shallow aquifer by a rock layer that does not allow much water to pass through (Figure 2). Some of the high capacity municipal wells in the area tap into this deep aquifer while others use water from the shallow aquifer.

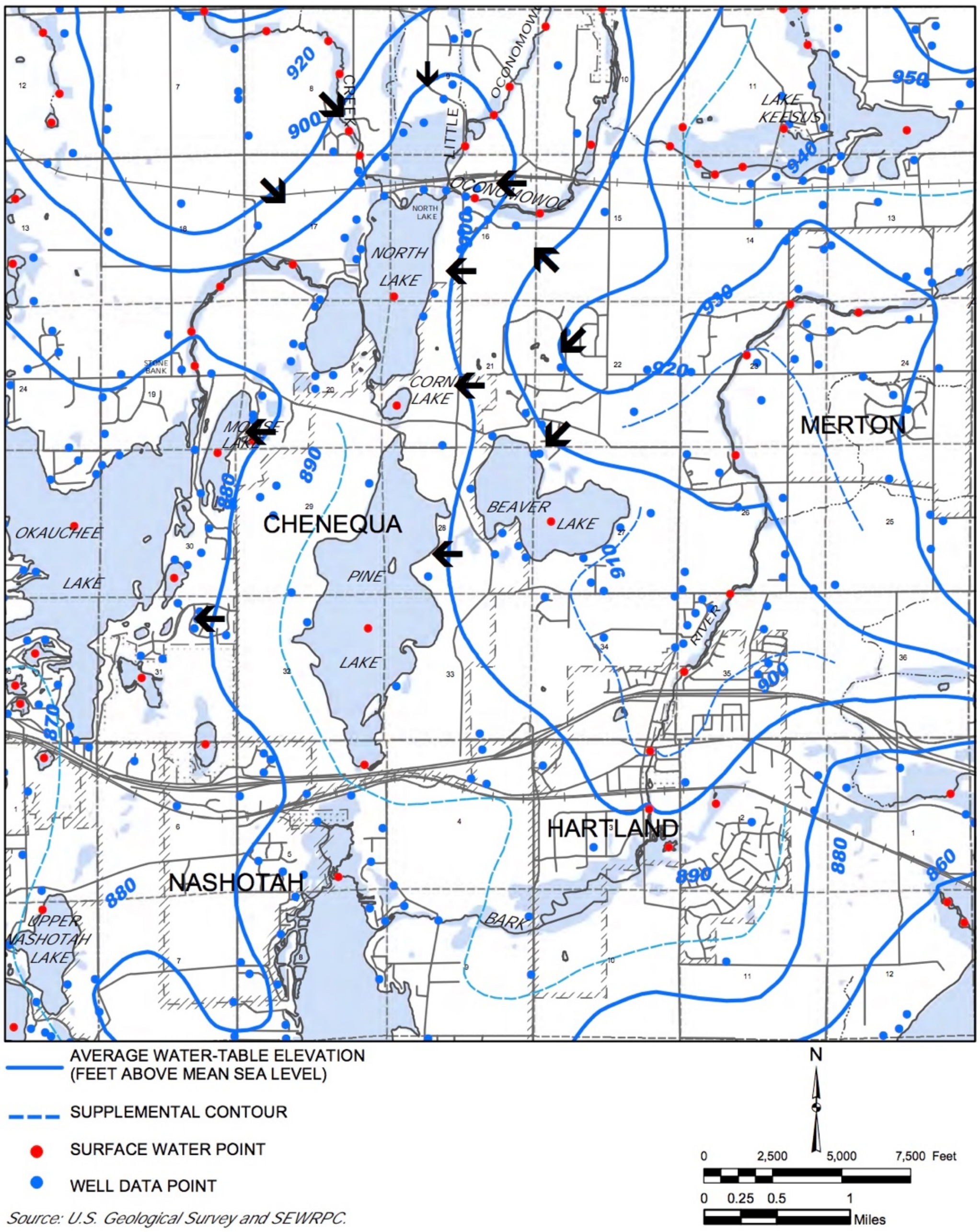

Figure 1: Direction of groundwater flow and water table elevation in the Pine and Beaver Lakes area (SEWRPC 2014).

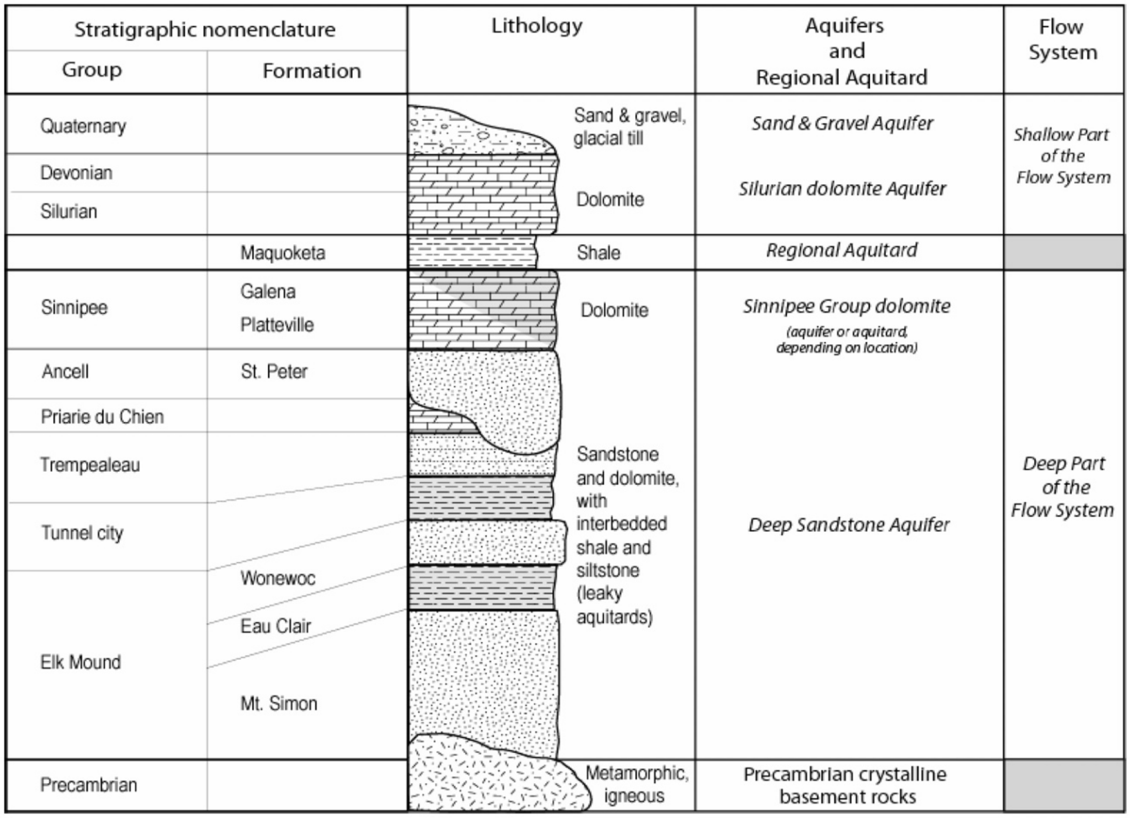

Figure 2: Underground structure and associated shallow and deep aquifers in Waukesha County (SEWRPC 2005)

The key to maintaining a consistent water level in Beaver Lake is to ensure that the water level in the shallow aquifer is not drawn down to a point where the flow from the springs into the lake is less than the water evaporating, seeping out or running out of the lake. The water balance for Beaver Lake is based on studies by Carman (1988) in which he measured seepage into and out of the lake directly using seepage meters. It is estimated that on average 1,300 acre-feet of groundwater flows into the lake while precipitation adds 890 acre-feet for a total inflow of 2,190 acre-feet. Water flows out of the lake by seeping out of the bottom of the lake at an annual rate of 460 acre-feet, evaporates from the lake surface at 810 acre-feet per year and each year 920 acre-feet flow through a culvert into Pine Lake. In order to maintain this water balance for Beaver Lake it is critical to maintain a consistent inflow of ground water from the shallow water aquifer. The main considerations for sustaining a consistent shallow water aquifer are to retain recharge areas where rainfall can soak into the ground and avoid excessive water removal by pumping. Although we cannot control rainfall we can preserve recharge areas and carefully control development of surfaces that water can't percolate through (impervious surfaces) like parking lots, roads, driveways and rooftops. Managing the percent of impervious surface is a challenge for local zoning authorities and municipal planners.

Organizations such as the Southeastern Wisconsin Regional Planning Commission (SEWRPC) and the United States Geological Survey (USGS) work cooperatively with local municipalities to develop plans to protect and monitor ground water. In June of 2014 SEWRPC released Community Assistance Planning Report Number 315 *A Water Resources Management Plan for the Village of Chenequa, Waukesha County, Wisconsin.* This document is a comprehensive compilation of information on surface and ground water in and around Beaver Lake. Based on this information, the report provides the following recommendations for effective management of groundwater resources.

1. Continuing management and inspection (at two- to three-year intervals) of onsite Sewage disposal systems.
2. Conjunctive management of groundwater and surface water resources.
3. Introduction of periodic monitoring of domestic water supply wells for [bacterial] water quality and other potential Lake pollutants such as phosphorous and chlorides.
4. Continued monitoring of groundwater levels.
5. General protection of groundwater recharge areas. (SEWRPC 2014)

Regular monitoring of groundwater levels is critical since this resource is not readily visible as are surface waters. With regular groundwater monitoring, subtle changes in subsurface flow possibly resulting from increased high capacity well pumping could be detected prior to causing a decline in lake level. This is particularly important during years of lower than normal rainfall when input to the lake would be reduced and evaporation from the lake would increase.

This concern about high capacity wells pumping water from the shallow water aquifer reducing lake levels in the Chenequa area was addressed in 2010 by the development of a USGS ground water simulation model (Feinstein et al. 2010). This study was a collaborative effort between the village of Chenequa, SEWRPC, Wisconsin DNR and USGS. The simulation model was used to predict the impact of various weather and pumping conditions on local lake levels. "The results of this simulation indicated that placement of a high capacity well along the boundary between the City of Delafield and Village of Chenequa would have a minimal influence on the surface water resources of the Village; rather, the primary impact of such withdrawals would affect the Bark River and its associated surface waters" (SEWRPC 2014). This model thus provides a framework to allow municipalities to evaluate the impact of establishing additional high capacity wells in the shallow aquafer.

The USGS modeling results were based on potential variation from average weather and pumping from the shallow water aquifer by existing wells as of 2010. The average weather conditions used were 32 in/year precipitation to lakes, 29 in/year evaporation from lakes and 8.5 in/year average recharge to the water table. The pumping rate from the shallow water aquifer in 2010 in the model area (Figures 3&4) was a total of 854 gal/min. The model simulated changes to surface water and ground water under a variety of conditions. The variables used in the model were precipitation, evaporation groundwater inflow and outflow as well as surface water inflow and outflow. Rainfall amounts and pumping rates were varied and simulations were run to determine potential impact on lake level. A test well pumping at 47 gal/min was drilled down to 200 ft. (Figure 4) in order to determine actual impacts of increased pumping from the shallow water aquifer. In this way simulated numbers could be compared to actual changes in pumping rates to provide verification of simulation results.

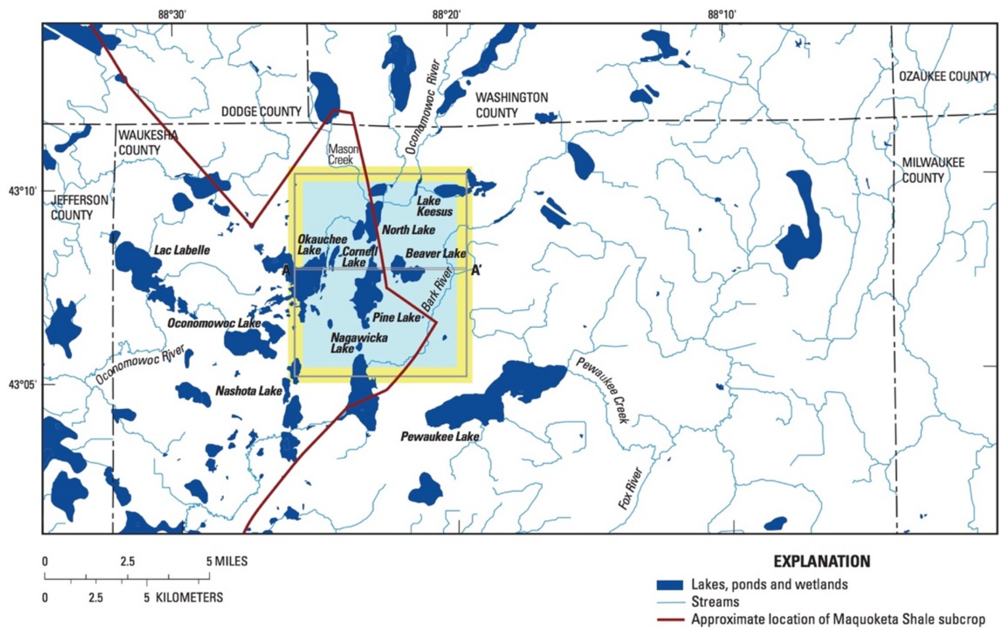

Figure 3: USGS ground water simulation model boundaries (Feinstein et al. 2010)

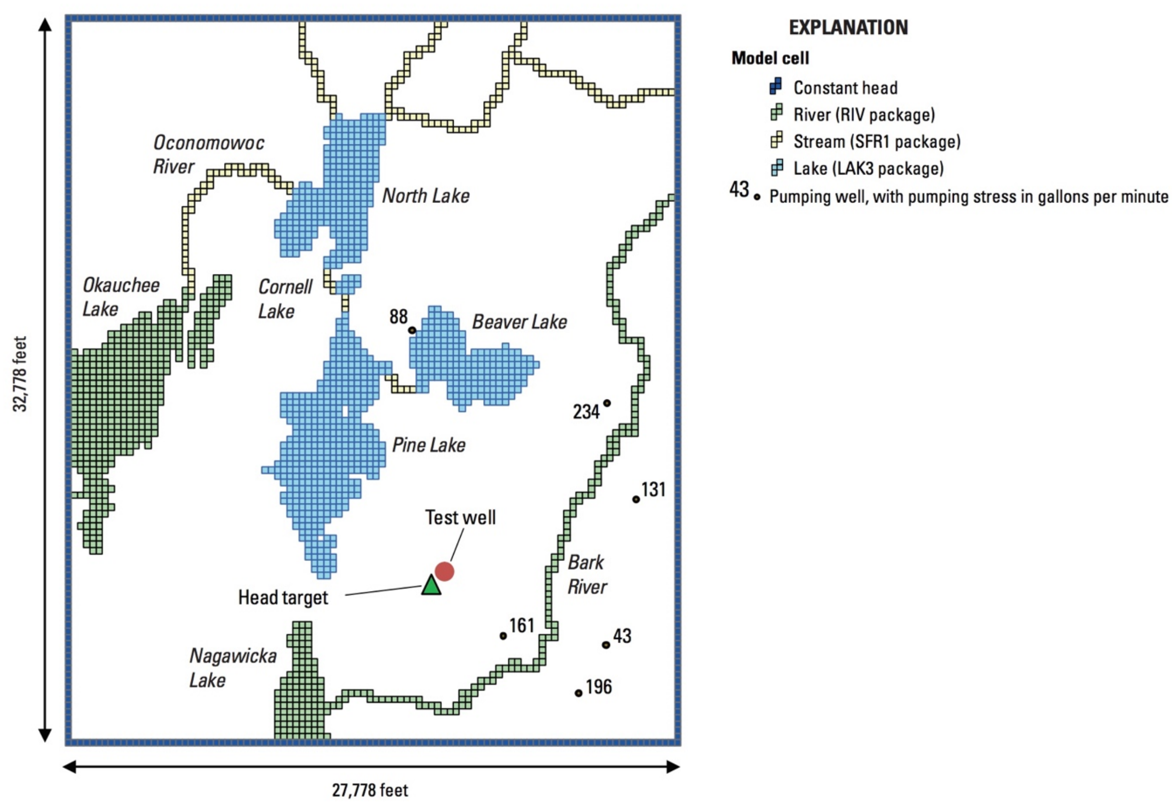

Figure 4: Shallow aquifer pumping locations and pumping rates in the USGS simulation model area (Feinstein et al. 2010).

The results of these simulations under various conditions showed relatively little change in the level of Beaver Lake over a five-year period (Tables 1-3). The impact of five years of simulated dry conditions reduced the lake level by 0.65 feet and reduced outflow into Pine Lake by 80% (Table 1). Simulation of five years of increased pumping at 47 gal/min and 200 gal/min from the shallow aquafer had very little effect on lake level (Table 2).

Table 1: Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes due to 5 years of dry weather conditions. (USGS 2010)

Location	Total pumping in child model: Average weather conditions [1], base run (854 gal/min)	Total pumping in child model: Dry weather conditions [2], base run (854 gal/min)	Difference in lake stage
Lake stage, feet above NGVD 29:			
Beaver Lake	909.62	908.97	- 0.65 ft
Pine Lake	900.27	896.62	- 3.65 ft
Cornell Lake	898.33	897.66	- 0.67 ft
North Lake	896.18	895.97	- 0.21 ft
Lake outflow, cubic feet per day:			
Beaver Lake	107,081	21,367	- 80 %
Pine Lake	59,122	≈ 0	- 100 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

Table 2: Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes with test well pumped for 5 years at 47 gallons per minute and at 200 gallons per minute under average weather conditions (USGS 2010).

Location	Total pumping in child model in average weather conditions [1]		Difference in lake stage	Total pumping in child model in average weather conditions [1]		Difference in lake stage
	Base run, 854 gal/min	Base run + 47 gal/min = 901 gal/min		Base run, 854 gal/min	Base run + 200 gal/min = 1,054 gal/min	
Lake stage, feet above NGVD 29:						
Beaver Lake	909.62	909.60	- 0.02 ft	909.62	909.56	- 0.06 ft
Pine Lake	900.27	900.24	- 0.03 ft	900.27	900.15	- 0.12 ft
Cornell Lake	898.33	898.28	- 0.05 ft	898.33	898.12	- 0.21 ft
North Lake	896.18	896.18	- 0.00 ft	896.18	896.17	- 0.01 ft
Lake outflow, cubic feet per day:						
Beaver Lake	107,081	105,935	- 1 %	107,081	102,251	- 5 %
Pine Lake	59,122	57,198	- 3 %	59,122	50,744	- 14 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

Based on these results it appears that dry weather conditions have a much greater impact on lake level than increased pumping rate. In order to evaluate this a simulated comparison was made between existing pumping rate in average weather conditions and an increased pumping rate of 47 gal/min under dry weather conditions (Table 3). This comparison showed that increased pumping under dry conditions only impacted lake level 0.01 foot more than just the dry conditions (Table 1).

Table 3: Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes with test well pumped for 5 years at 47 gallons per minute under dry weather conditions (USGS 2010).

Location	Total pumping in child model		Difference in lake stage
	Average weather conditions [1] Base run, 854 gal/min	Dry weather conditions [2] Base run + 47 gal/min = 901 gal/min	
Lake stage, feet above NGVD 29:			
Beaver Lake	909.62	908.96	−0.66 ft
Pine Lake	900.27	896.54	−3.73 ft
Cornell Lake	898.33	897.64	−0.69 ft
North Lake	896.18	895.97	−0.21 ft
Lake outflow, cubic feet per day:			
Beaver Lake	107,081	19,657	82 %
Pine Lake	59,122	≈ 0	100 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

This could lead to the conclusion that additional pumping rates have very little impact on the level of Beaver Lake. It is important, however, to consider the broader picture which is described in both SEWRPC (2014) and USGS (2010) reports. Both of these documents emphasize the importance of maintaining areas of natural recharge for the shallow water aquifer (Figure 5). If recharge areas are covered with impervious surfaces, like roads and parking lots, as the area develops the replenishment rate of the shallow aquifer will be reduced. If the replenishment rate cannot keep up with the pumping rate of wells in the area then pumping will have an impact on the level of Beaver Lake. In addition, this simulation model is a sub model of a much broader simulation for Southeastern Wisconsin (Feinstein et al 2005 & SEWRPC 2008). Changes in the broader model resulting from development and changing weather conditions will impact local simulations. These groundwater models serve as a tool to forecast possible impacts of changes in pumping rates and other local conditions. Since simulations are approximations of what might occur, it is important to regularly monitor ground water levels and lake levels to become aware of trends that are actually occurring.

Dr. Douglas Cherkauer, Professor Emeritus UW Milwaukee, who worked with SEWRPC to develop the ground water flow model for southeast Wisconsin, has coordinated an effective groundwater monitoring program for the Village of Richfield. This program includes homeowners, businesses and government entities who have volunteered to have their well levels monitored on a bimonthly basis. A total of 43 wells distributed somewhat evenly around the shallow water aquifer in the Richfield area were selected for this program. In addition, water levels in streams and lakes in the area are regularly monitored. Together these two sets of data are used to generate water table maps (Figure 6) that can be updated on a regular basis. Levels in these wells have been monitored manually however, an automated system produced by Wellntel of Milwaukee (www.Wellntel.com) is being installed. This system sends a sound wave into the well, records all the returning echos, and sends that signal via radio waves to a gateway in the house adjoining the well. The gateway is connected to the cloud via a WiFi link, where the signal is processed to separate the water surface reflector from all others in the well, and is then posted on a Wellntel dashboard (Cherkauer 2019 personal communication). In addition, historical data can be compiled to allow an ongoing assessment of the water levels in various parts of the region (Figure 7). With this type of program in place the impact of local development on groundwater can be directly evaluated.

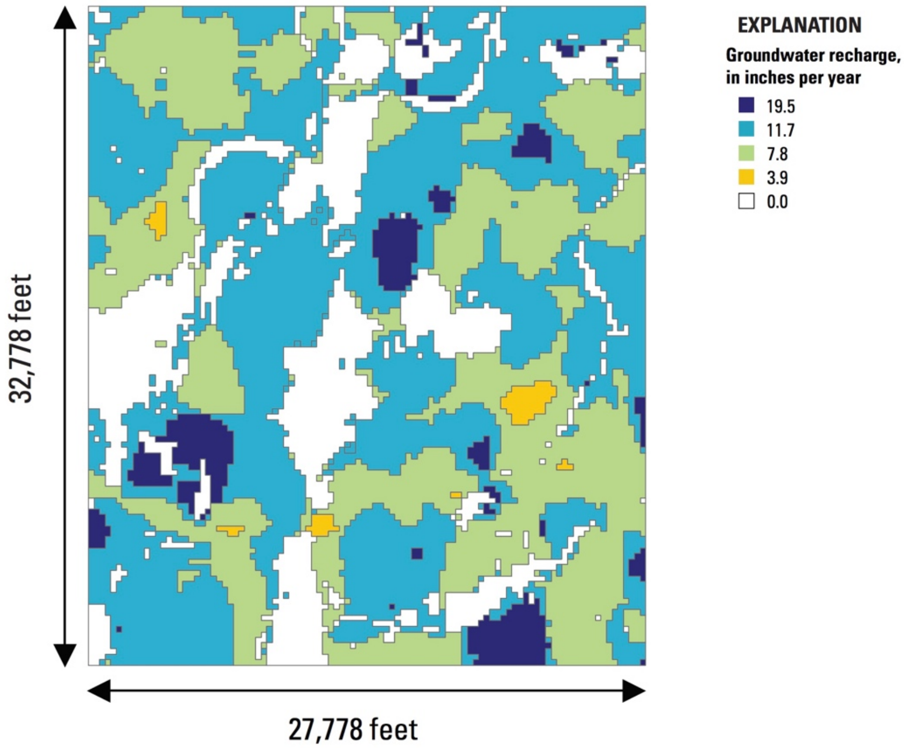

Figure 5: Ground water recharge areas within the simulation model area (USGS 2010).

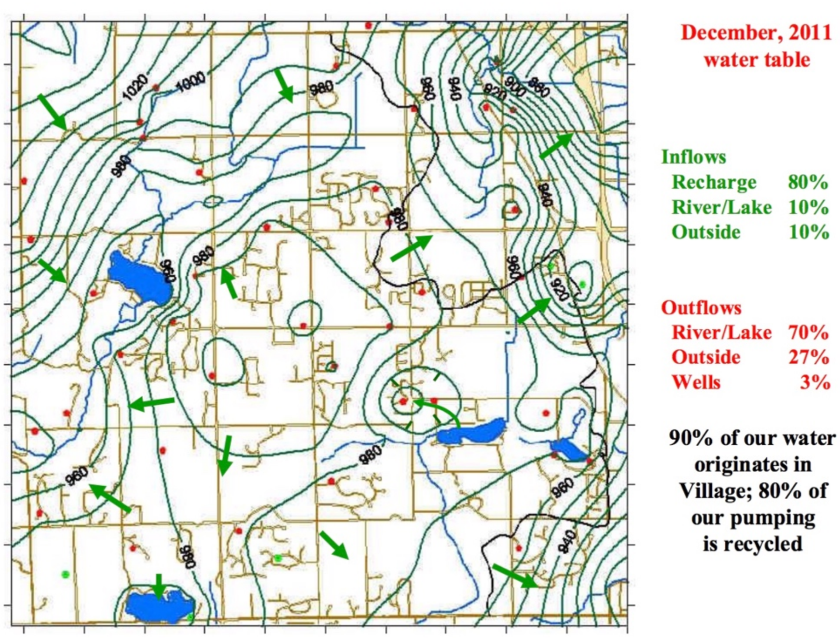

Figure 6: Richfield water table map and groundwater budget for December 2011 (Cherkauer 2013).

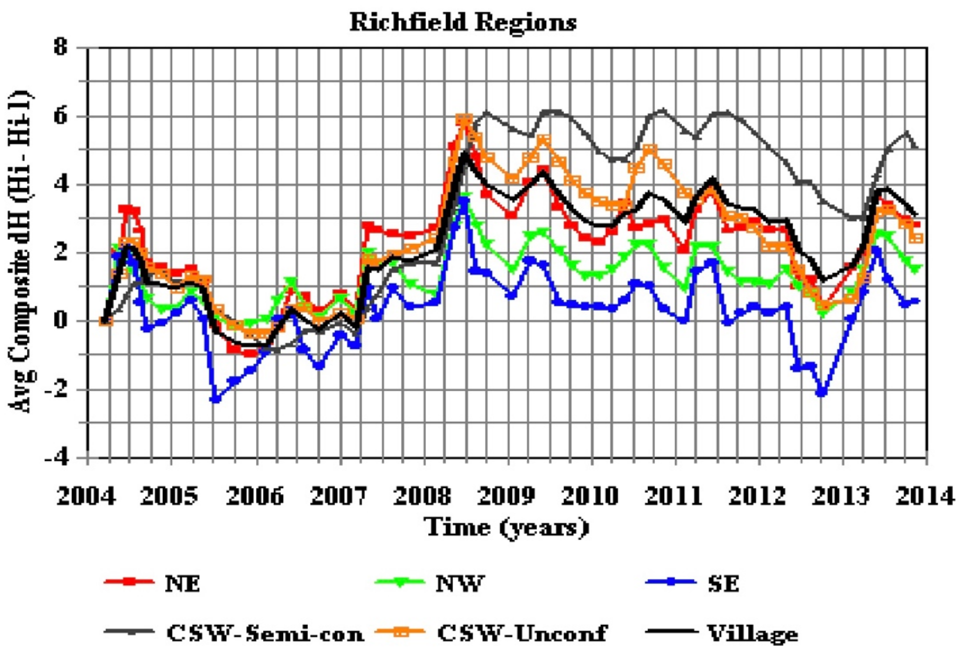

Figure 7: Changes in average groundwater elevation in the Richfield regions (Cherkauer 2013).

The Village of Richfield also developed a Groundwater Protection Ordinance to minimize impacts to groundwater as the area develops. This ordinance includes a Groundwater Protection Permit that restricts drawdown on newly developed properties and nearby surface water bodies. Through a combination of monitoring and management of development Richfield has been able to reverse a decline in groundwater levels in the region.

Concerned citizens and municipalities in the Beaver Lake area have worked to maintain green areas and monitor surface and groundwater levels. The development of a groundwater model specifically for this area (Feinstien et al 2010) and the extensive water resources plan (SEWRPC 2014) are a testament to a commitment to maintain the quality and quantity of ground water in the region. Ordinances and zoning restrictions not only need to protect groundwater recharge areas but also extraction of ground water. One of the key components of the SEWRPC regional water supply plan (SEWRPC 2010) was a recommendation that studies related to the siting of all new high-capacity wells include analysis of potential impacts to the shallow water aquifer and preference should be given to site locations that are less likely to produce adverse impacts upon surface water bodies. It is not clear what the current extent of groundwater monitoring is in the Beaver Lake region. Beaver Lake levels are recorded on a monthly basis by the Village of Chenequa based on a brass stream gauge bolted to the foundation of a "wet" boathouse. The lake elevation associated with this gauge was verified as part of the development of a Beaver Lake Bathymetric Map (Koeller & Hogan 2018). There are numerous methods for measuring lake levels however all of these methods require regular calibration based on the type of gauge being used for Beaver Lake. Compilation of lake level data and groundwater monitoring based on designated wells in the region would provide insight into ongoing trends in water resources in the area. Citizens in the area could work in collaboration with local municipalities to develop a system similar to that being used by the Village of Richfield.

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