Groundwater pumping near Geneva Lake: Evaluating its effect on the lake

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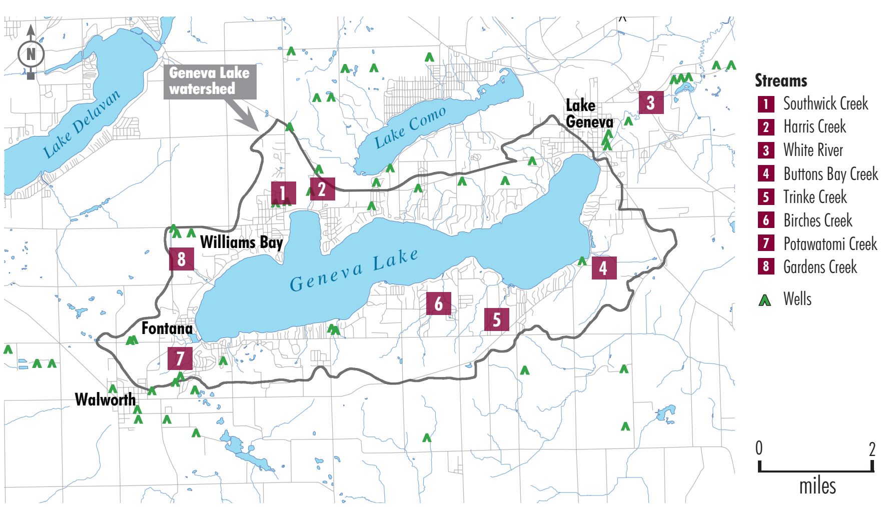
Residents and businesses in and near the communities of Walworth, Fontana, Williams Bay and Lake Geneva depend on groundwater for their water supply. Stakeholders in these communities also have a great interest in the health and quality of Geneva Lake and the many streams and springs in the watershed.

Groundwater and surface water systems are interconnected; together they comprise the hydrologic system. Groundwater sustains flow to wells and also discharges to lakes, streams and wetlands. Pumping from wells can reduce the quantity of groundwater that feeds nearby surface water features. Pumping also can alter the pathways that groundwater follows through the subsurface, changing the direction of groundwater flow.

Groundwater is a finite resource. Communities must address questions involving the need and expense of water supply while sustaining the quality and quantity of groundwater that flows to lakes and streams. Science-based information about a hydrologic system can inform such discussions.

This fact sheet describes findings from a groundwater flow model developed for Geneva Lake and the surrounding region in Walworth County, Wisconsin (figure 1). The model is a tool, and we can use it to understand and manage groundwater and surface water resources. The model provides answers to questions such as: How much groundwater flows into and out of Geneva Lake? What is the effect of current pumping on the lake and nearby streams? What will happen to the lake if pumping increases or if there is a drought?

Figure 1. **Geneva Lake study region including nearby communities, tributary streams, surface watershed area, and municipal wells.**



Using computers to simulate groundwater flow

Groundwater flow through sediments and rock is difficult to see and measure. However, groundwater flow follows the laws of physics, and it can be described with mathematical equations. Computers are routinely used to solve these equations with a groundwater flow model. The flow model simulates a real-world hydrologic system, in this case groundwater in the Geneva Lake region. Limitations in the available data and in the computer programs necessitate some simplification and approximation of the actual system. Although there is uncertainty in the model results, the model provides information and insights at a scale and accuracy sufficient for water resource managers to make informed decisions.

Several years ago, the Wisconsin Geological and Natural History Survey and the U.S. Geological Survey (USGS) in cooperation with the Southeastern Wisconsin Regional Planning Commission (SEWRPC) developed a computer model

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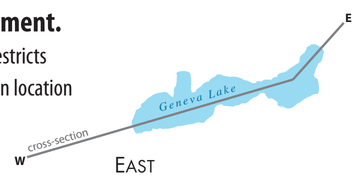
of groundwater flow in southeastern Wisconsin. This model was adapted to investigate groundwater–surface water interactions in the vicinity of Geneva Lake. The Geneva Lake model encompasses 312 square miles, but it has more resolution, meaning more detail, in the area of Geneva Lake, its tributary streams, and wells in nearby communities.

The groundwater flow model simulates three key details about water movement: (1) groundwater recharge; (2) flow through aquifers; and (3) discharge to streams, lakes, and water wells. We constructed the Geneva Lake model by assigning characteristics of the hydrologic system to the computer program. This information includes the depth and thickness of geologic layers, aquifer permeability, well locations and pumping rates, and locations of streams and lakes. Developed with the computer program MODFLOW (McDonald and Harbaugh, 1988), the model simulates a shallow sand and gravel aquifer, a bedrock aquitard, and a deep sandstone aquifer (figure 2). We used 796 groundwater level measurements and 13 measurements of stream flow to calibrate the model. Model calibration involved adjusting variables within reasonable ranges until the model-predicted groundwater levels and stream flow results were in good agreement with the measurements.

The model simulates the water table and gives estimates of groundwater flow rates to streams, lakes, and wells. Following calibration, the model can be used to simulate how the hydrologic system will respond to stresses such as drought conditions or changes in pumping rates.

Figure 2. Cross-section showing groundwater movement. The Maquoketa shale layer that underlies Geneva Lake and eastward restricts flow of groundwater from the shallow to the deep aquifer. Cross-section location shown at right.



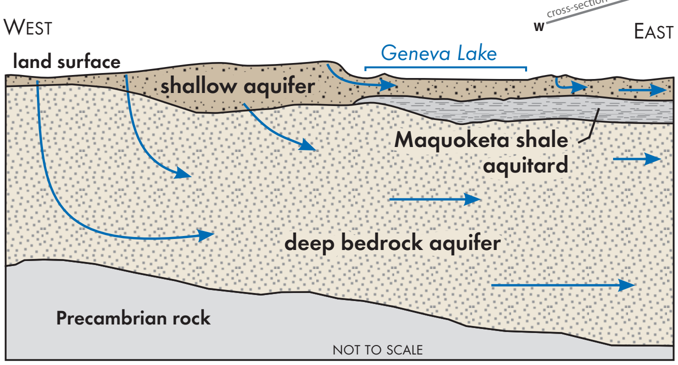
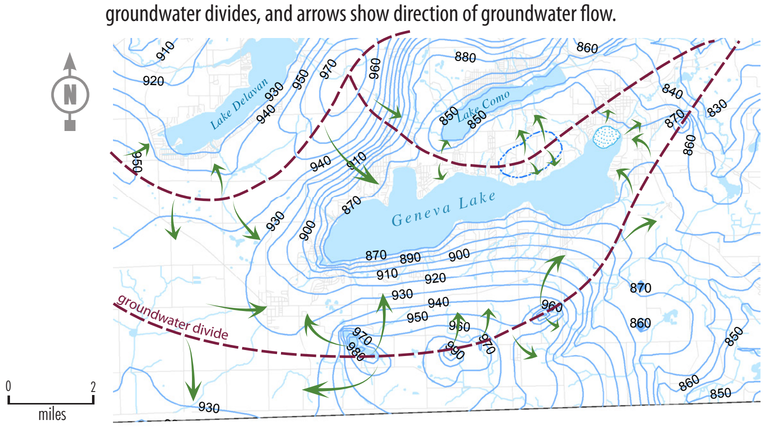


Figure 3. Regional water table map. The contour lines give approximate water table elevation, dashed lines mark groundwater divides, and arrows show direction of groundwater flow.



Geneva Lake area hydrologic setting

Groundwater flow through the Geneva Lake region

The hydrogeology in the Geneva Lake region includes a shallow aquifer (figure 2) comprised of discontinuous and very permeable sand and gravel deposits. Glacial till, consisting primarily of low-permeability clay and silt, is interbedded with the sand and gravel in many locations. The shallow aquifer also includes a thin layer of dolomite that underlies the sand, gravel, and till. The contrast in the permeability of the coarse sand and gravel to the till controls local-scale groundwater flow paths from ridge-tops to nearby springs, streams, and shallow wells.

The Maquoketa shale underlies the shallow aquifer and extends eastward from Geneva Lake. A deep bedrock aquifer, consisting of up to 2000 feet of layered sandstone and dolomite, underlies the shale. The shale is an aquitard, which is a low-permeability rock that restricts the vertical flow of groundwater from the shallow to the deep aquifer. Where the shale is absent west of the lake, the shallow and deep aquifers are closely connected. This is an important recharge area for the deep aquifer because groundwater flows downward and laterally in this region, allowing shallow groundwater to reach the deep system. Relatively impermeable Precambrian rock forms the bottom of the deep aquifer.

The water table map (figure 3), based on model results, shows the approximate elevation of the water table near Geneva Lake; each contour line on the map connects points of equal water-table elevation. The arrows on the map indicate that shallow groundwater flows from the west and south towards Geneva Lake. Along the topographic ridge between Lakes Geneva and Como, a groundwater divide delineates the area where

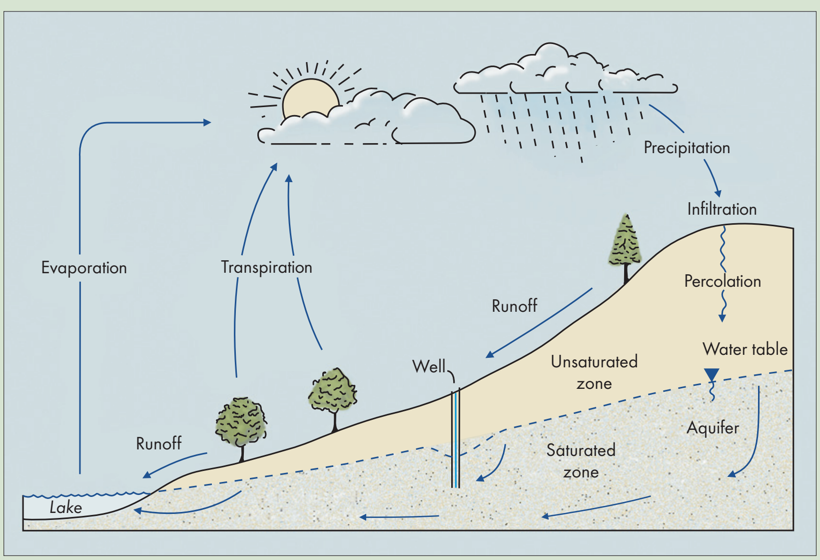
UNDERSTANDING GROUNDWATER FLOW AND DISCHARGE

The earth's hydrologic cycle includes the many forms that water takes as it passes through the atmosphere and earth. As shown in figure 4, the cycle includes precipitation which either runs off the ground surface or percolates through soil and sediment to become groundwater. Groundwater flows through geologic materials and eventually discharges to wells or surface water bodies, such as lakes and streams. Water returns to the atmosphere by evaporation from surface water or transpiration by plants.

Groundwater is contained in aquifers, which are saturated geologic materials (such as sand and gravel deposits or a bedrock layer) that yield water to wells. Permeability is a measure of an aquifer's ability to transmit groundwater; permeability depends on the nature of the sediment or rock through which the water is flowing. Sand and gravel are porous, and have high permeability.

The natural direction of groundwater flow is downward in response to gravity, from areas of higher water-table elevation to lower water-table elevation. Groundwater flows through aquifers from recharge areas to discharge areas. The uplands, where the water-table elevation is higher, tend to be areas where water infiltrates the ground and recharges groundwater. Lowland streams, lakes, wetlands, and springs are typically areas of groundwater discharge. Water wells are manmade points of groundwater discharge. Pumping lowers the water level in the well, and groundwater then flows into the well. Pumping from wells diverts groundwater that would otherwise discharge to nearby lakes and streams.

Figure 4. The hydrologic cycle.



groundwater flows north toward Lake Como from the area where flow is south towards Geneva Lake. Groundwater at the northeast end of the lake flows to the northeast, along the White River valley.

Sources of water to Geneva Lake

The "water budget" of a lake is an accounting of all the water that flows into and out of the lake. Sources of water entering Geneva Lake (inflow, in budget terms) include precipitation, surface water flow from tributary streams, runoff from along the shoreline, and groundwater seepage from aquifer sediments (figures 5a and 5b). Water leaves the lake system (outflow) through evaporation and discharge over a dam into the White River. A small amount of lake water also seeps into the underlying aquifer at the northeast end of the lake. We used the model to simulate inflows and outflows to Geneva Lake under two scenarios: predevelopment (non-pumping) and 2006 pumping conditions. Pumping reduces the total volume of water flowing through the lake by about 4% because wells divert groundwater that would otherwise discharge to the lake. The model predicts that the lake level will not drop below the top of the dam due to pumping, and the proportions of sources and sinks of water to the lake are similar under pumping and non-pumping scenarios.

An additional scenario simulated with the model includes a 30% increase in pumping rates at municipal wells, based on population projections for 2035 (SEWRPC Technical Report 11). This increases the amount of groundwater diverted from the lake and decreases the lake budget by about 4.5% from predevelopment conditions.

The model can be used to demonstrate the sensitivity of Geneva Lake to potential long-term changes in climate. The simulation shows that during very wet years flow through the lake almost doubles. A higher proportion of water enters the lake from streams and runoff, and more water discharges to the White

River. The model also predicts that during very dry years the amount flowing into and out of the lake would be reduced by about 65%. In this scenario, the lake level drops below the dam and there is no discharge to the White River. In a drought, groundwater becomes even more important to the lake budget because of the extreme reduction in precipitation. This suggests that any increase in pumping associated with dry weather could exacerbate the loss of inflow to the lake. In the case of drought, water managers can make further use of the model to evaluate potential benefits of water conservation and reduced pumping.

Groundwater contribution to streams

Wells located near streams can intercept groundwater that would otherwise discharge to that stream. Base flow is the groundwater contribution of flow in streams. The model can be used to compare simulated base flow to streams under various pumping rates (figure 6). Pumping has reduced stream flows on the west side of the lake at streams that are near high-capacity wells (Harris, Gardens, and Potawotami Creeks). Simulated base flows to Birches, Trinke and Buttons Bay are affected to a lesser extent by pumping because they are far from any high-capacity wells. A 30% increase in pumping from municipal wells further reduces base flow to nearby streams. The model indicates that groundwater discharge to these streams could be increased by conserving water (less pumping) or by shifting pumping from shallow to deep wells.

Geneva Lake groundwater contribution area

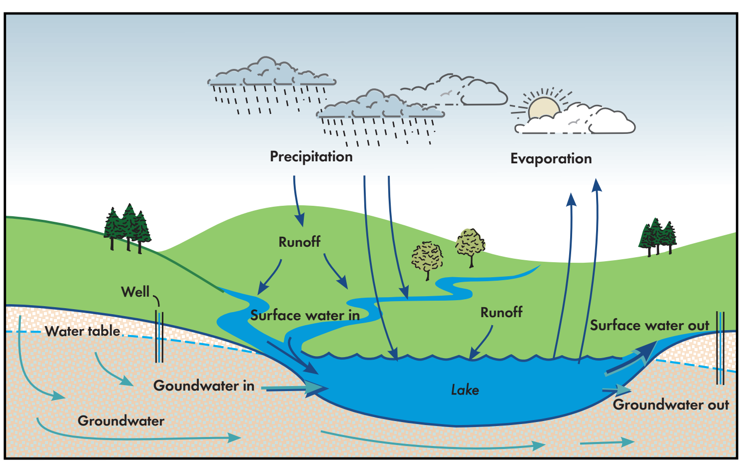
The groundwater flow model can be used to identify where groundwater comes from that enters a well, lake, or stream. Known as the groundwater contributing area, this is the area on the land surface where precipitation and snowmelt infiltrate to the water table, flow through the aquifer, and discharge to a specific well or surface water feature. Several factors influence the location and size of the contributing area, such as the direction of groundwater flowpaths, the permeability of the aquifer, and the location, depth and pumping rates of wells.

The predevelopment (non-pumping) groundwater contributing area for Geneva Lake, illustrated in figure 7, extends west and south of the lake and is much larger than the surface watershed. The current condition groundwater contributing area, also shown in figure 7, is affected by pumping from wells west and north of the lake. These wells intercept groundwater that would otherwise discharge to the lake, which alters the shape of the contributing area, shifting it farther west. Overall, the current contributing area is smaller than in predevelopment conditions. The lake receives 9% less inflow from groundwater and stream base flow compared to the predevelopment simulation. In contrast, wells that supply the City of Lake Geneva lie outside both the groundwater contribution area and the surface watershed. These wells capture groundwater from the White River basin, which is downgradient of the lake. The model indicates that pumping from these wells has a minor impact on the balance of outflows from the lake, increasing lake seepage to groundwater by about 0.5%. However, these wells have no impact on the total volume of the flow into and out of the lake.

Use and limitations of model results

Understanding the simplifications and assumptions made in any groundwater model is critical in applying results to real-world questions. The accuracy of the Geneva Lake groundwater model is limited by the accuracy of the data available for calibration. This model is well-calibrated, and it provides reliable results. However, there is always the possibility that a geologic feature, such as a fracture or other highly permeable pathway, significantly affects groundwater flow in the vicinity of a specific well, spring

Figure 5a. Sources of water entering and leaving Geneva Lake.



Source: Adapted from Hydrology and Water Quality of Geneva Lake, Walworth County, Wisconsin, *USGS, 2002.*

Figure 5b. Simulated percentages of water entering and leaving Geneva Lake under 2006 pumping conditions.

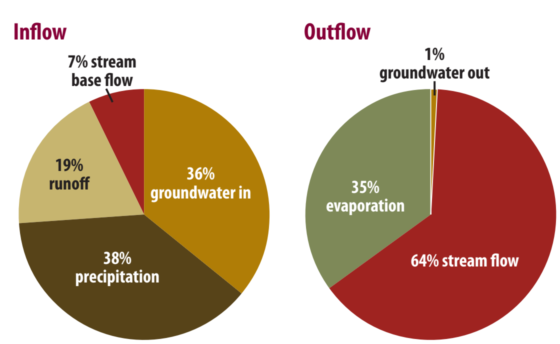
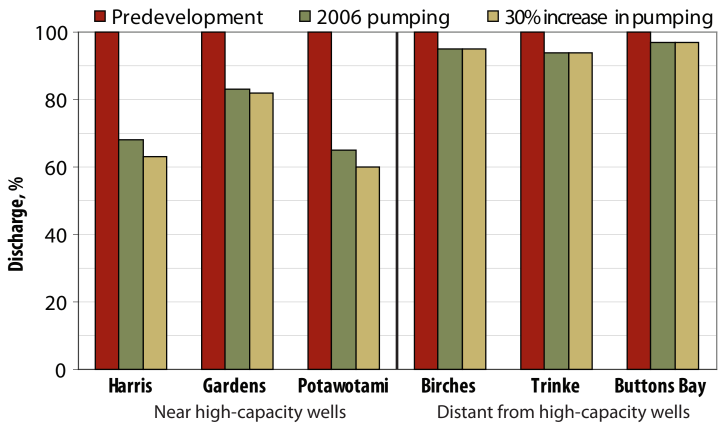


Figure 6. **Impact of municipal well pumping on stream flow.**



or stream, but is not simulated in the model. Although use of the model results does not guarantee that any particular well or stream will respond to change as predicted by the model, the insights and the information gained from the model can improve management of groundwater and surface water resources.

Other simplifications made in developing the Geneva Lake groundwater flow model include ignoring seasonal variations in water table elevation and short-term changes in flow paths caused by temporary changes in recharge or pumping. For example, the current model simulates the average decrease in stream base flow caused by average pumping rates. However, in reality, base flow varies seasonally in response to natural, short-term fluctuations in water table elevation.

WHERE DOES THE WASTEWATER GO?

When assessing the impact of pumping, it's important to consider what happens to the wastewater. Is it ultimately returned to the local hydrologic system or is it permanently removed?

The communities of Walworth, Fontana and Williams Bay pipe wastewater to treatment plants located outside of the surface water basin. Thus, after use and treatment, this water is discharged to streams in other watersheds, removing it from the Geneva Lake hydrologic system.

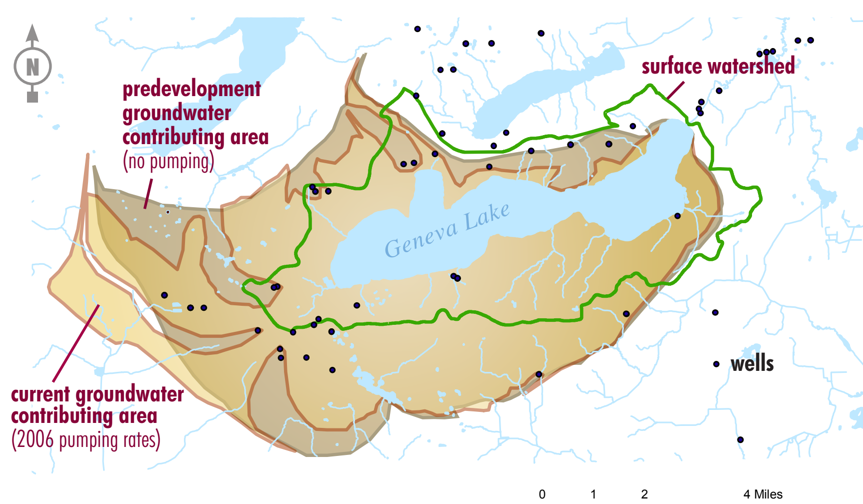
In contrast, wells operated by the Lake Geneva Water Utility are located outside the lake's groundwater contributing area. Through recharge of treated wastewater at the Lake Geneva infiltration ponds, a majority of the groundwater pumped from these wells is returned to the local hydrologic system, within the White River basin.

Protecting the quality and quantity of the lake and streams

Water quantity and water quality issues are often closely related. The groundwater flow model addresses groundwater *quantity* by simulating flow between groundwater and surface water, but it does not address water *quality* issues. For example, most homes in unincorporated areas of the lake basin rely on on-site water wells and septic systems. These private domestic wells pump very low volumes of water and do not have a significant impact on groundwater quantity in the basin. For this reason, they are not simulated in the model. However, septic system effluent can be a source of groundwater contamination and may impair lake water quality.

Water resource managers and stakeholders in these communities often balance complex trade-offs between water quality and quantity issues. As discussed above, diversion of wastewater beyond the Geneva Lake basin removes groundwater from the local hydrologic system. However, this may be beneficial to lake water quality if the diversion decreases the nutrient load to the lake.

Figure 7. **Surface watershed and groundwater contributing areas.**



Robertson and others (2002) and SEWRPC (2008) report on recent studies of lake water quality. This information can be used along with flow model results to make informed decisions affecting water quantity and quality issues.

Information about groundwater resources in Wisconsin

At the Wisconsin Geological and Natural History Survey, scientists collect, analyze, and publish basic data about the natural resources of Wisconsin. We can assist in regional-scale evaluation of groundwater resources and, if sufficient information is available, may assist in evaluating issues pertinent to a specific area, such as Geneva Lake. Geologic and water table maps are available from the WGNHS for many counties in Wisconsin, and are listed on our web site: WisconsinGeologicalSurvey.org.

Acknowledgements

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Dan Winkler

Surface water discharge from Geneva Lake to White River.

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