

WELL WATER for RURAL RESIDENTIAL SUBDIVISIONS:



Using groundwater flow models to evaluate options for water supply

Throughout much of Wisconsin, there is growing concern about water resource issues in relation to rural residential development. In areas not served by public water supply, developers often propose that a private well be drilled at each residence. Local government officials responsible for reviewing these proposals often have little information on groundwater conditions with which to evaluate the proposed development.

Concerns about residential developments include the *quality* of groundwater – will water from new wells meet drinking water standards? Potential sources of groundwater contamination include land use practices such as residential septic systems, road salt, and fertilizers or pesticides applied to agricultural fields and residential landscapes. Public water supply systems are routinely tested for contaminants and are subject to state and federal drinking water requirements. However, testing of residential water wells is left to the homeowner, and most well owners do not regularly test their well water quality.

In addition to water quality, proposed developments in rural areas raise questions about groundwater *quantity*. These concerns often focus on the impacts of new wells on nearby streams, lakes and existing wells.

Groundwater Modeling: An example from rural Sauk County

Computer simulations of groundwater flow can be used to improve the design of water supply systems for rural subdivisions. This fact sheet describes the use of such a model to simulate the hydrogeologic conditions in a rural area in Sauk County, Wisconsin. Model results illustrate consequences of different options for residential water supply in a proposed subdivision. Developers, planners and local government officials can use this science-based information to determine which options best suit community needs. While the example presented here pertains to geologic and hydrogeologic conditions in north central Sauk County, the methodology may be applied to many areas in Wisconsin where groundwater quality, groundwater quantity, land use and development are at issue.

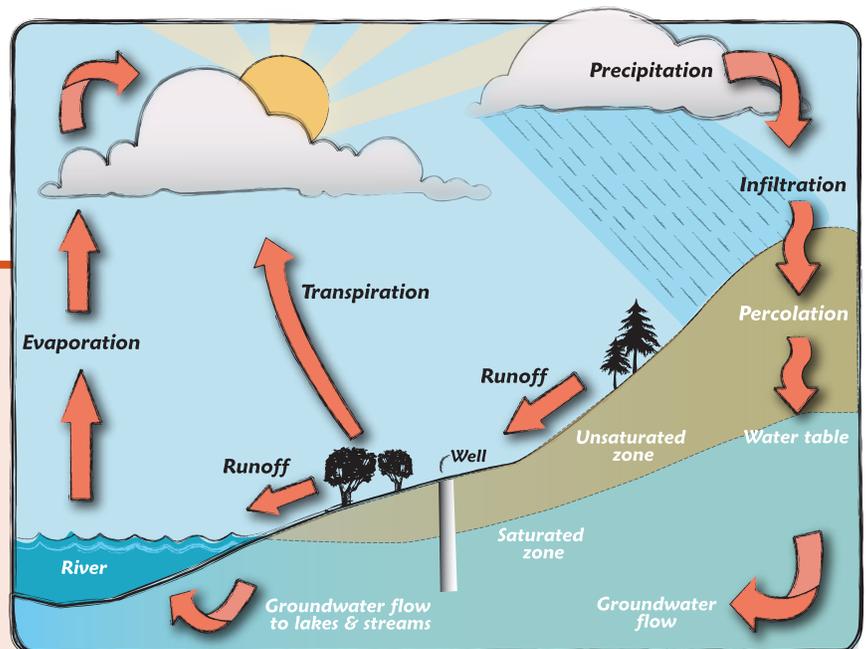
Using computers to simulate groundwater flow

Groundwater flow through sediments and rock is difficult to see and measure, but groundwater flow follows laws of physics described by mathematical equations. Computers are routinely used to solve these equations and simulate groundwater flow systems. Although computer models of groundwater flow are a simplification of the natural hydrologic system, model results provide useful information about well water quantity and quality.

Groundwater flow models can simulate groundwater recharge, flow through aquifers, and discharge to streams, lakes and water wells. A model is constructed by assigning aquifer characteristics

within the computer program. These characteristics include aquifer permeability and thickness, well locations and pumping rates, and locations of streams and lakes. The model is calibrated, or adjusted, until the model-predicted water levels closely match observed conditions. Model results typically consist of a water table elevation map and groundwater flow rates to streams and lakes. Once calibrated to local conditions, a groundwater model is used to simulate the response of water levels and flow rates to various stresses, such as drought conditions or changes in pumping rates from wells.

FIGURE 1:
The hydrologic cycle.



Groundwater: A Primer

The earth's hydrologic cycle includes the many forms that water takes as it passes through the atmosphere and earth. As shown in Figure 1, 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 rivers. Water is returned to the atmosphere by evaporation from surface water or transpiration by plants.

Groundwater can travel rapidly (at rates up to several feet per day) through sand and gravel or porous sandstone aquifers. Much slower rates of groundwater flow (as little as an inch per year) can be expected in clayey deposits and poorly-fractured bedrock. Regardless of the rate at which groundwater flows, the natural direction of groundwater flow is 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.

Computer models are also used to identify the area on the land surface that supplies groundwater to a particular well or set of wells. The contributing area or “capture zone” of a well is that part of the land surface where precipitation and snowmelt infiltrate through surface sediments and flow through an aquifer to a well (Figure 2). The location and size of a well’s capture zone depend on the direction of natural groundwater flow, the pumping rate at the well, and aquifer characteristics (such as its thickness and permeability). After delineating the capture zone of a well, current or proposed land uses can be evaluated to determine the potential impacts on water quality at the well. For example, Figure 3 illustrates two neighboring residential lots developed without consideration of well capture zones. If the direction of groundwater flow and the well capture zones had been delineated prior to final design, wells could have been sited to avoid potentially intercepting discharge from nearby septic system drain fields.

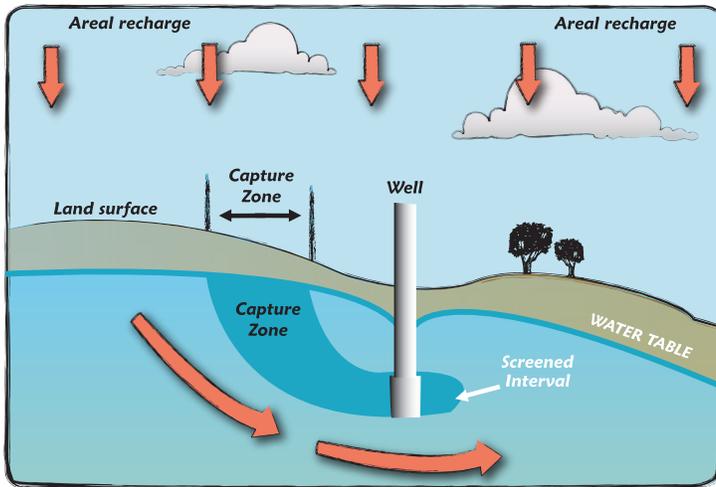


FIGURE 2:
The “capture zone” of a well.
Adapted from Franke et al. 1998

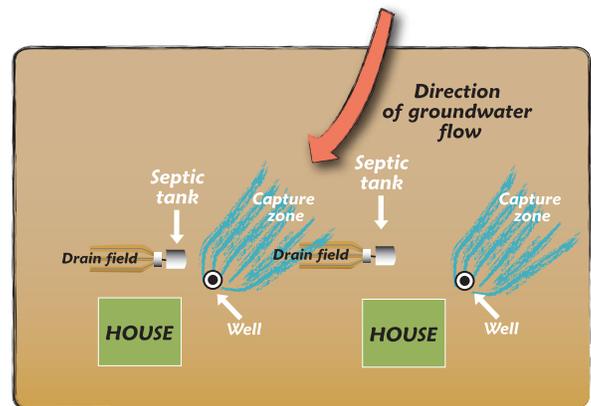


FIGURE 3:
Septic systems are potential sources of contamination to nearby wells.

Case Study: Subdivision proposal and site evaluation

In 2005 the Sauk County Planning Department requested that the Sauk County groundwater model be used to demonstrate flow to water wells for a proposed subdivision (Figure 4, next page). Located on a bluff in uplands near the Baraboo River, the proposed development was 2,000 feet east of Lake Virginia. Well construction records from existing residential wells were used to evaluate local geologic and hydrogeologic conditions. The well records show that surficial deposits of sand range in thickness from four to 42 feet; the sand is interbedded with clay at some locations.

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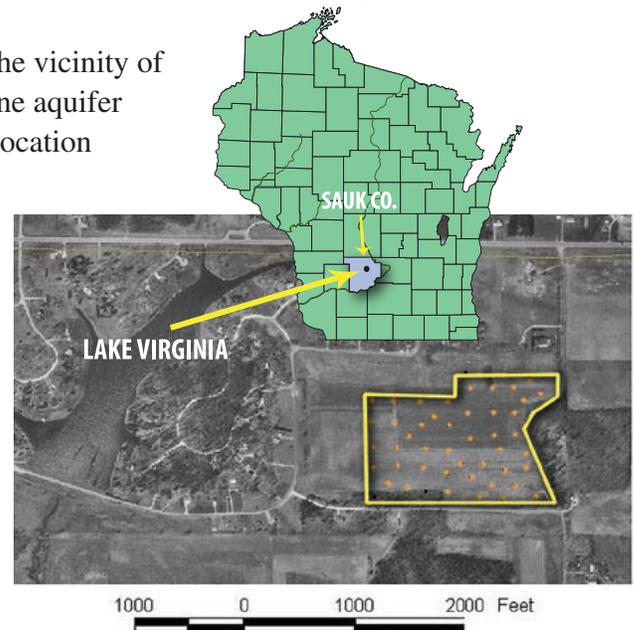
Groundwater flow models used in this study

Several years ago, the Wisconsin Geological and Natural History Survey and the U.S. Geological Survey developed a computer model of groundwater flow in Sauk County (Gotkowitz and others, 2005). Developed with a computer program called “GFLOW” (Haitjema, 1995), the model incorporates estimates of aquifer thickness and permeability, recharge, and locations and elevations of streams and lakes. The model also includes well locations, well depths and pumping rates. The data available for model calibration included 580 groundwater-level measurements and seven measurements of stream flow. Water levels calculated with the calibrated Sauk County model provide a good match to water levels measured in the aquifer.

These deposits are underlain by sandstone. Depth to water in the wells ranges from 22 to 70 feet below ground surface, indicating a relatively shallow water table. Well construction in the area appears consistent with state requirements (Wisconsin Administrative Code, 1994), typically consisting of 30 to 60 feet of casing installed into bedrock; total depths of the wells range from 65 to 125 feet below ground surface.

The records confirm that the hydrogeologic conditions in the vicinity of Lake Virginia are consistent with the homogenous sandstone aquifer simulated in the regional groundwater flow model. At the location proposed for development, the model simulates a water table elevation of about 886 feet above sea level (the equivalent of a depth to water of 52 feet below ground surface), with flow direction to the southwest, toward the Baraboo River.

FIGURE 4: Site location. Inset shows Lake Virginia, near-by houses and farm fields. The location of the proposed 36-acre development (outlined in yellow) and 48 residential wells (orange dots) are east of the lake.



Applying the model results

The model was used to investigate several alternative water supply designs for the subdivision. In the first scenario, the model was used to simulate capture zones of wells located on each of the lots in the subdivision. The second scenario was developed to evaluate constructing the wells with casing extending deeper into the bedrock aquifer. A third option, that of constructing a single community well to supply water to all of the homes, was also evaluated.

1. A private well for each home

In accordance with the subdivision proposal, 48 wells were placed over a 36-acre area in the model. An estimated average water use rate for a four-person household of 350 gallons per day was assigned to each of the wells in the model. The capture zones show that each well receives its water from a small area located close to the well (Figure 5). The model predicts a small capture zone for these wells because the aquifer is very thick and permeable relative to the small volume of water typically pumped at a household well. The simulated capture zones and the nature of the aquifer in this area (shallow and very permeable) suggest that water quality could be impacted by nearby septic systems and lawn-care products applied to the land surface near the well. Impacts to groundwater quality from historical land use, such as agricultural application of nitrate or pesticides, could also affect water wells developed on this property.

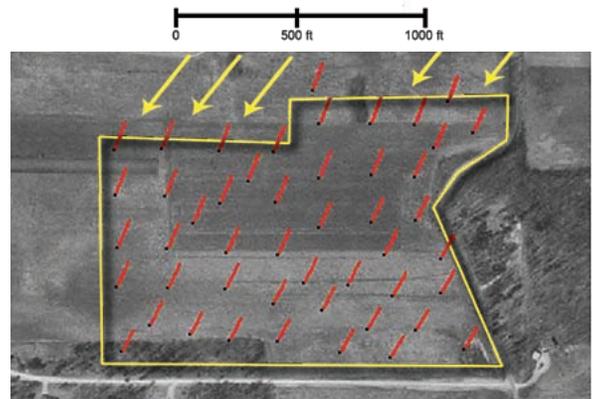


FIGURE 5: Model-simulated capture zone for each well is shown in red. Arrows indicate direction of groundwater flow.

2. Depth of well casing

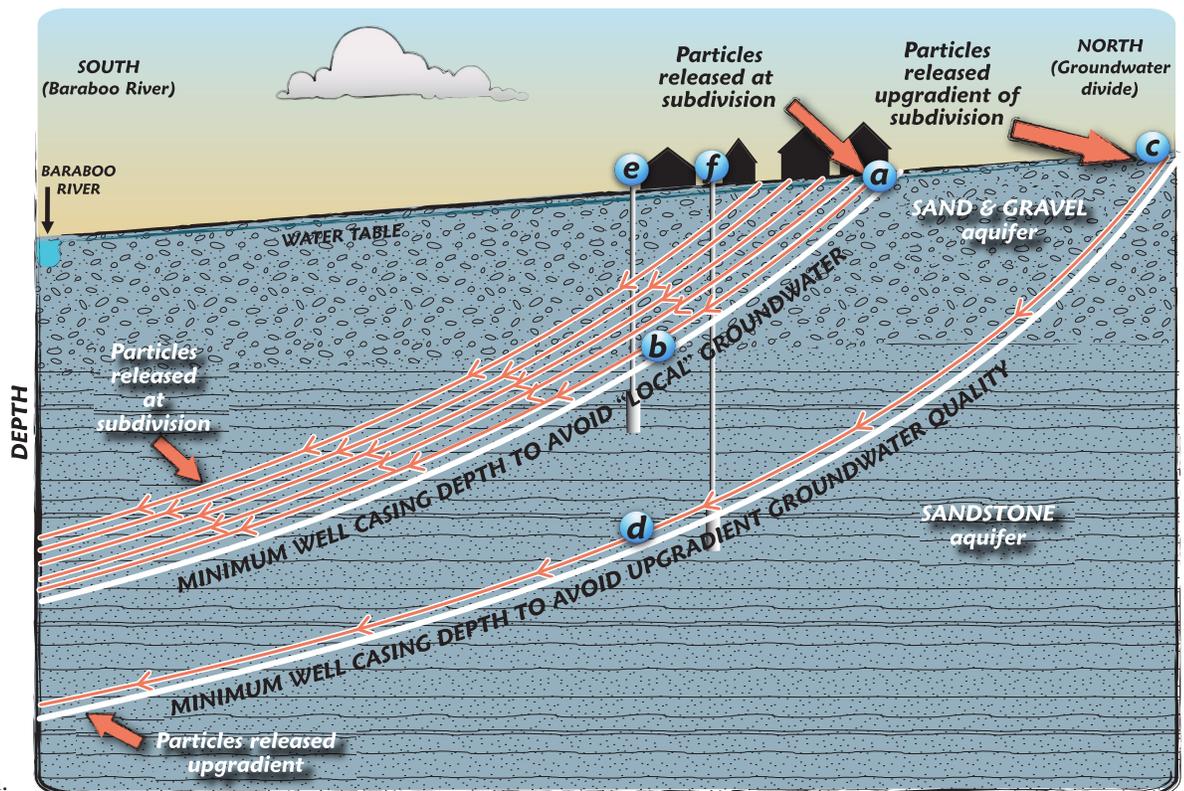
The results presented above suggest that wells drilled in the subdivision in compliance with state-required construction practices would primarily receive shallow groundwater. Residential wells constructed in this hydrogeologic setting would benefit from deeper well casings that prevent nearby septic systems from impacting groundwater that flows to the wells. A second computer model was developed to simulate the vertical paths of groundwater within the aquifer and to estimate the effect of casing depth. The computer program MODFLOW (McDonald and Harbaugh, 1988) was calibrated to match groundwater flow along a slice, or cross-section, through the aquifer (Figure 6). The cross-section simulated with the model extends from the top of the ridge 1,000 feet north (up-gradient) of the proposed subdivision, where the water table is at its highest elevation in this region. The southern (down-gradient) edge of the cross-section reaches the Baraboo River, where the water table elevation is at its lowest elevation.

The model results demonstrate that precipitation and snowmelt that recharge the water table at the north end of the subdivision (a) flow to a depth of about 55 feet beneath the water table prior to reaching the southern (down-gradient) boundary of the development (b). Recharge from the up-gradient (northern) edge of the flow field (c), at the top of the ridge, is about 175 feet below the water table when it reaches the subdivision (d).

These simulations of the groundwater flow system indicate that wells cased deeply into the aquifer would reduce the risk of water quality impacts from nearby sources of shallow contamination. Given the degree of accuracy of the model, a reasonable interpretation of the results is that constructing a well with 100 feet of casing below the water table (and ensuring the use of appropriate grouting techniques to seal the casing) would help protect the wells from land-use impacts within the subdivision (e). More than 200 feet of properly grouted casing would be required to protect the well from sources of contamination located up-gradient of the development (f).

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FIGURE 6: These model results are used to estimate the minimum casing depth required to pump groundwater recharged upgradient of the proposed subdivision.



3. A community well

The regional groundwater flow model was used to simulate the capture zone for a single community well placed in the subdivision (Figure 7). The pumping rate assigned to this well in the model was 16,800 gallons per day (assuming 48 households each using 350 gallons per day). The capture zone is larger than those simulated for a single home because of the larger pumping rate at the community well. Using a community well in the subdivision would result in a single capture zone that could be more easily protected than those created by individual residential wells. For example, the capture zone of the community well (plus a buffer space to account for uncertainty in the model result) could be set aside as open space over which land use activities could be controlled or limited. A deeply drilled and cased community well may be more economically feasible than deeply cased individual wells. These advantages might not overcome the disincentives that developers face in providing a community water system, such as the expense of piping from the well to each home and the legal and financial covenants necessary to maintain the community system.



FIGURE 7: The arrow indicates the direction of groundwater flow. The capture zone of a community well supplying 48 households with water is shown in blue.

Using the model results

The groundwater flow models used in the Sauk County study were calibrated to regional conditions, and provided a good match to the measured depth to ground water in the vicinity of the proposed development at Lake Virginia. The model simulations reasonably approximate groundwater conditions at the site and provide a sound technical basis for land use planning. For example, these results can be used to recommend a minimum separation distance between wells and septic systems within the proposed subdivision, to suggest a minimum casing depth for the residential wells, or to illustrate potential benefits of a community water supply system. The model results also demonstrate that groundwater pumping at the density proposed for this subdivision will not cause a decline in the lake level at nearby Lake Virginia.

Limitations of a computer model

Understanding the simplifications and assumptions made in any groundwater model is critical in applying results to a real-world problem. The accuracy of the Lake Virginia groundwater model is limited by the amount and accuracy of the data used to calibrate the model. For example, There is always the possibility that a significant geologic feature, such as a fracture or other high-permeability pathway not simulated in the model, might affect groundwater flow to a well. Use of this model to inform well construction and siting at new homes does not guarantee that any particular well will always pump groundwater of high quality, but the insights and information gained from the model can lead to improved well siting and design.

Groundwater Terms

Aquifer: a layer of geologic material (such as sand and gravel deposits or a bedrock layer) that is saturated and yields water to wells.

Aquitard: a layer of geologic material (such as clay or shale) that is saturated but yields almost no water to wells. Aquitards restrict the flow of groundwater through the subsurface.

Capture zone: the area of the land surface over which precipitation and snowmelt infiltrates through the ground, enters a groundwater system and eventually flows to a well. A capture zone is also referred to as “recharge area” of a well.

Discharge area: a place where groundwater flows, or “discharges” from an aquifer to a stream, lake, spring or wetland

Flow path: the path traced out by a given particle of water as it flows from one point in the groundwater system to another.

Fractures: a crack or fissure in the subsurface. A bedrock fracture can provide a pathway for rapid transport of groundwater and contaminants to a well.

Gradient: the difference in water pressure between two locations in the groundwater system; the gradient, or pressure difference, induces groundwater to flow from areas of higher water levels (higher pressure) towards areas with lower water levels (lower pressure).

Groundwater flow system: a series of aquifers and aquitards, and groundwater recharge and discharge areas, within an area of hydrogeologic interest.

Groundwater model: a computer program that performs mathematical calculations describing a groundwater flow system.

Homogeneous: a property that is uniform. For example, a homogeneous sandstone aquifer has similar permeability everywhere within the aquifer.

Hydrogeology: the science of groundwater and geology.

Permeability: a measure of how easily fluid moves through a sediment or rock.

Recharge: precipitation, snowmelt, or other sources of water that infiltrate to the water table through unsaturated soil and sediment.

Residential well: a well drilled to supply water to a single residence located in an area not served by a water utility or community well.

Unsaturated zone: soil and rock in which pore spaces are not fully water-saturated. The unsaturated zone is above the water table.

Water table: the depth (or elevation) at which soil or rock is fully saturated with water. This is also the elevation to which water rises in a well.

Well casing: pipe installed in a borehole extending down from the ground surface to prevent collapse of soil and geologic materials into the well. The well is drilled deeper, beyond the casing, and water can flow from the aquifer into the uncased portion of the well.

Groundwater information for land use planners in Wisconsin

There are a wide variety of hydrogeologic conditions across Wisconsin. Regional and local conditions must be considered in evaluating groundwater flow to wells at any location. The methods presented in this fact sheet can be applied to most hydrogeologic settings. Geologists and hydrogeologists at the Wisconsin Geological and Natural History Survey collect and analyze basic data about the geologic and groundwater resources in Wisconsin. Water table maps and groundwater resource evaluations are available from the WGNHS for many counties in Wisconsin, and are listed on our web site: www.uwex.edu/wgnhs/. We can assist in regional scale, county-wide evaluation of groundwater resources. Engineering and environmental consultants across the state assist developers and local communities in site-specific groundwater issues, such as the one described here.

Information about testing water wells and incorporating groundwater into land use planning is available through water programs of the Central Wisconsin Groundwater Center, University of Wisconsin Extension. www.uwsp.edu/cnr/gndwater/.

More information regarding state regulations that apply to residential wells and community water systems is available at the Wisconsin Department of Natural Resources website, www.dnr.wi.gov/org/water/dwg.

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Additional copies of this document may be obtained from the Central Wisconsin Groundwater Center:
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www.uwsp.edu/cnr/gndwater/info/index.htm

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