Source Water Assessments and Land Use Planning

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Abstract

Communities often find themselves having to make important land use decisions without the benefit of a detailed understanding of the source of their drinking water or its sensitivity to potential contamination. This is perhaps truer of groundwater than surface water sources. The Source Water Assessment Program (Safe Drinking Water Amendments, 1996) is designed to provide communities with information they can use to develop drinking water protection plans. Specifically, the assessment identifies (delineates) the resource, inventories potential contaminant sources within the recharge area, and analyzes the susceptibility of the drinking water to those potential contaminant sources. Each of these elements can also help a community make more informed land use decisions. Typical land use questions that can be addressed using the Source Water Assessments include (1) What land uses are located in the recharge area? (2) Is a particular land use up-gradient from the well or spring? (3) What is the vulnerability of the aquifer that supplies the community? (4) Where should the community locate a new well? (5) What is the direction of groundwater flow in the area? (6) Where is the source of our drinking water most sensitive to contamination? Although it is not able to provide a quantitative answer to all land use questions, the assessment results do provide the community with answers to most, or if not, can point specifically to what additional information is needed. The assessment allows local government officials to have a better understanding of their resource, helping them not only in making land use decisions, but also in responding to questions and concerns expressed by the public.

Introduction

Groundwater is not an obvious component of the hydrologic cycle (the "Forgotten Element of the Watershed"), yet it plays a critical role that includes supplying base flow to streams, lakes, and wetlands and as a source of drinking water for many communities. It wasn't that long ago that, with respect to land use planning, groundwater was viewed only as a source of drinking water for a community. Today we are aware of groundwater's vulnerability to contamination and now must consider the potential for pollution of the community's drinking water during the planning process.

Few resources are more valuable to a community than its drinking water supply. And yet for those communities that depend on groundwater, i.e., wells and/or springs, local officials often find themselves having to make important decisions about land use that may potentially conflict with safe drinking water without having sufficient information or established procedures to adequately do so. Many land use decisions would be better served if local planning authorities had more information regarding the nature of the groundwater system that serves as the community's and/or rural resident's drinking water source.

The answer to many hydrogeological questions requires data collection and interpretation by a professional groundwater hydrologist (hydrogeologist), however others can be answered, or at least refined, using available information. One of the most important sources of information to a community is the results of the Source Water Assessment Program, a federal mandate to states to determine the sources of drinking water for public systems, identify potential contaminant sources that might affect the drinking water, and estimate the susceptibility of the drinking water to those potential contaminants.

The Source Water Assessment results fall into the realm of technical planning in that they can be considered support studies allowing the assessment of the potential impact of proposed land uses within a drinking water source area. The assessments support both decision-making and sustainability planning efforts.

Whether evaluating a proposed land use application, or just responding to a citizen request, City officials and planners are faced with many questions regarding land use and drinking water quality. The most common question that local officials face is "Will a particular land use activity affect our aquifer's water quality"? Specific questions might include:

- The city's well is located in an industrial area. How can we estimate the drinking water supply's vulnerability to contamination?
- An area within the city's or county's jurisdiction is currently zoned for ¼-acre lots. The homes will be served by individual on-site systems for treating waste. Will this impact the aquifer?

- A gravel operation is proposed to be located within a half mile of the city's well. Will groundwater move from that facility towards our well?

- The city's wastewater treatment lagoons are within a half mile of the city's well. Will microbial contamination reach the well?

In many areas, data are available to address the above questions at a level that can be useful in deciding future actions. An important point is recognizing the limitations of data acquired as indicated in this report and knowing when more detailed studies by the appropriate professional is necessary. A rigorous evaluation of each of these questions above is beyond the scope of this manual and of most non-hydrogeologists. The purpose of this guidance is to provide the planner or city official with information that will allow them to better perform their day-to-day jobs as well as the basic tools that can be used as indicators of the impact of land use practices on the aquifer. The following sources of information may be very useful in deciding whether additional assistance is needed.

1. **Published groundwater studies**. These are often published by agencies such as the state agency in charge of water resources or the U.S. Geological Survey and are readily available from the agencies or from local university libraries. Lists of publications are often available on websites, e.g., www.usgs.gov/pubprod.

2. **Unpublished consultant reports**. These are generated by consultants on behalf of communities or private facilities in response to specific questions of groundwater availability, water rights or contaminant occurrence. State agencies will generally be able to provide information concerning these reports.

3. **University theses**. Universities within the state that have active graduate programs that include hydrogeology may have useful information. Research conducted by graduate students in these programs may provide important information regarding groundwater conditions in the area. Check the specific websites for the school under geology, geoscience, or hydrology.

4. **Well reports**. In most states, well constructors are required to submit well reports on wells they construct. Well reports include important information regarding how the well was constructed, the type of subsurface geology, water levels, and groundwater production. Well constructors are not hydrogeologists, however, and the quality of the information provided varies. But well reports are often the only source of information available in an area.

5. **Well constructors**. Few know more about an area's groundwater than local well constructors. These individuals have been in the business of

groundwater production for years and are very knowledgeable regarding the occurrence of groundwater within their specific area. This information includes depth to producible water, nature of the aquifer, well capacities, and the occurrence, if any, of non-potable water.

6. **Regional watermasters**. The Oregon Water Resources Department (OWRD), with support from individual counties, provides information regarding water availability, water rights, well construction, and a host of other water-related issues through regional watermasters. Because of their history in an area and the data they have accumulated over time, watermasters are an excellent source of local groundwater information. Regional watermaster contacts can be obtained from OWRD's website.

7. **County environmental health departments**. To varying degrees, counties provide support for groundwater and drinking water issues, including water availability and potability.

8. **Source Water Assessment Reports**. These reports are often generated by the agency that oversees public water systems in the state. Information provided by the assessment includes the nature of the groundwater system in the immediate area of the public water system, potential sources of contamination in the area, and the susceptibility of the drinking water source to contamination. The Source Water Assessment reports are a valuable resource to the community with respect to protecting their drinking water supply. This is particularly so, given that the assessment usually draws data from a number of sources, such as those listed above.

Using available data

These sources of data may be useful in two ways. First, they may allow the planner or city official to confidently make a decision regarding the potential impact of a given land use. Second, when used in conjunction with the methods described in this report, the information may provide the planner with the background that will help them better understand and evaluate the information provided to them in a study completed by professionals in the field of hydrology.

Planners should treat their hydrogeologic evaluations as preliminary assessments. Does the information indicate that the potential for the development of a water quality problem is remote? An example would be where the data indicate that groundwater from a potential source of contamination is moving away from the community well rather than towards it. Or perhaps a proposed well is in an entirely different aquifer than that supplying residents and therefore will not interfere with their water supply. If, however, the data available are not conclusive and there is still a question, call in the consultants.

Groundwater overview

To make use of data that are available about local groundwater, it is necessary to have a general understanding of how the groundwater machine works. Space does not allow a detailed description of the groundwater system here. More detailed discussion of the following is provided in basic groundwater manuals such as Heath (1983), Marsh (1997), Leopold (1997), Dunne and Leopold (1978) and any introductory geology textbook. A manual on groundwater basics, the *Groundwater Training Manual*, is available on the OHA-Drinking Water Services Groundwater web page.

For purposes of this discussion, we want to briefly summarize several important points regarding the groundwater system:

Where does groundwater come from?

Virtually all groundwater originates as precipitation, infiltrating downward through the soil. Gravity is the driving force for this downward movement. Depending on the type of material just below the surface, the water may move down through individual sediment and soil particles, e.g., through sand, fractures, or fractured bedrock.

What is an aquifer?

An aquifer is typically defined at two levels: physically, in terms of its makeup, and functionally in terms of a supply of water. From the physical aspect, an aquifer can be defined as any geologic material, e.g., sand, gravel, bedrock, etc., that has open spaces, such as pore spaces between grains or as fractures, and that these open spaces are filled with water. From the functional perspective, this geologic material must be of sufficient permeability to be able to yield water to a well at a rate that meets the supply needs.

Aquifers typically are also characterized as being either confined or unconfined. This refers to whether groundwater can readily move in the vertical sense (unconfined) or is confined below a layer of relatively impermeable geologic material. Unconfined aquifers have as their recharge area the land surface directly above them and the water in the aquifer is at or near atmospheric pressure. The water table represents the top of an unconfined aquifer. Confined aquifers are generally recharged in nearby(?) areas of higher elevation, often several miles or more from the well. Water in the aquifer is typically under pressure and will rise in the well bore above the level of the aquifer, i.e., it exhibits artesian behavior.

It is not uncommon for there to be multiple aquifers at depth. For example, an unconfined aquifer may exist near the surface while one or more confined aquifers may be encountered at successively greater depths.

How does groundwater move?

The pressure that the groundwater is under, referred to as its hydraulic head, is the driving force for groundwater movement. Groundwater will move from an area where the head is higher to an area where the head is lower.

Hydraulic head can be thought of as the potential energy possessed by the water. Head consists of two components: elevation and pressure. The elevation head is the height of the groundwater above sea level, while the pressure head relates to the weight of the fluid above. Because water has a density of one gram per cubic centimeter, it is possible to express hydraulic head as the elevation of groundwater at rest, i.e., the elevation of the water table in an unconfined aquifer or the elevation the water rises to in a well in a confined aquifer.

Given that there may be several aquifers at depth, it is possible that each will possess a different head. As a result, groundwater may be moving in different directions and at different rates in different aquifers.

What is the relation between groundwater and surface water?

Groundwater is an integral part of the hydrologic cycle (see *Groundwater Training Manual*) and as such is intimately connected to surface water flow. Both water quantity and quality issues may arise for a well in an aquifer that is defined as being in hydraulic connection with surface water. An aquifer is considered to be in hydraulic connection with surface water when groundwater may move to or from the surface water source either through natural flow or under induced conditions, i.e., by a pumping well.

Both water quantity and water quality issues are of concern for groundwater that is in hydraulic connection with streams. From a water quantity perspective, a well may either be inducing seepage from a nearby stream because of the well’s pumping, or the well may be intercepting groundwater that would normally flow to the stream as baseflow. In either case, the action of the well is reducing flow in the stream.

From the water quality perspective, a well that induces water from a stream to flow to the well may also capture microbes, including bacteria, viruses, *Giardia* and *Cryptosporidium* with the water. Further, constituents released during a spill upstream from the well may be drawn into and persist within the aquifer because of the pumping well.

Groundwater flowing into a stream may be important in controlling water temperature and may provide dissolved constituents to the stream that are important in the overall quality of the stream.

How vulnerable is groundwater to pollution?

Factors that influence how vulnerable or susceptible groundwater is to pollution include both intrinsic characteristics of the soil and subsoil material above the aquifer, as well as the land use practices that are occurring at the surface.

The focus here is on the intrinsic factors, which include:

1. Depth to the aquifer,
2. Thickness and permeability of the soil zone,
3. Thickness and permeability of the vadose zone (the unsaturated material that separates the aquifer from the surface),
4. The nature of the aquifer, i.e., confined or unconfined, and
5. The presence of any rapid pathway that may allow contaminants to pass into the subsurface, e.g., improperly constructed wells, animal burrows, lava tubes, buried utility lines, etc.

Information provided by Source Water Assessments

Regulations concerning the quality of drinking water have a history of evaluation at the tap, i.e., monitoring water quality within the distribution system and if a problem shows up, then treat it. This approach was soon recognized as expensive and maintenance intensive. Plus, it was counter to other well-established and accepted procedures for taking care of something, e.g., dental checkups and car servicing, so that the problem would never occur in the first place.

Congress took the first major step in the preventative direction with the 1986 Amendments to the Safe Drinking Water Act (SDWA) by establishing the Wellhead Protection Program[1] (WHPP). The SDWA directed states to develop WHPPs that provide guidance to groundwater-based water systems so the systems could develop wellhead protection plans. The plans would be used by communities to minimize the risk of contamination of their drinking water supplies.

Specifically, all states are required to:

1. Delineate the source water protection area[2] (SWPA). For surface water sources it is the subwatershed region that contributes to the water body that contains the intake. For groundwater systems, it is the area at the

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[1] In Oregon, the term *wellhead protection* has been replaced with the more commonly used term d*rinking water source protection*.

[2] In Oregon, the term *source water protection area* has been replaced with the term *drinking water source area*.

surface that directly overlies that part of the aquifer that supplies water to the well or spring.

2. Inventory the potential contaminant sources within the SWPA.

3. Determine the susceptibility of the drinking water source to the potential contaminant sources.

Specifically, the Source Water Assessments will provide the following information to groundwater-based public water systems:

1. The surface area above the groundwater that supplies the wells or springs. This can be considered to be equivalent, in the planning sense, to the recharge zone.

2. What aquifer supplies water to the well? What are its characteristics?

3. The direction of groundwater flow in the aquifer

4. Factors that lead to the susceptibility of the source:
   a. PCS inventory
   b. Intrinsic factors, e.g., shallow unconfined vs. deep confined
   c. External factors that may be modified, e.g., well construction, chemical storage

5. Relation between surface water and groundwater

With the above information, the SWPA can be considered as a “special environment” in the planning process, having the same standing as wetlands, unique habitats, etc., and should be considered as such in environmental assessments.

Susceptibility of the aquifer

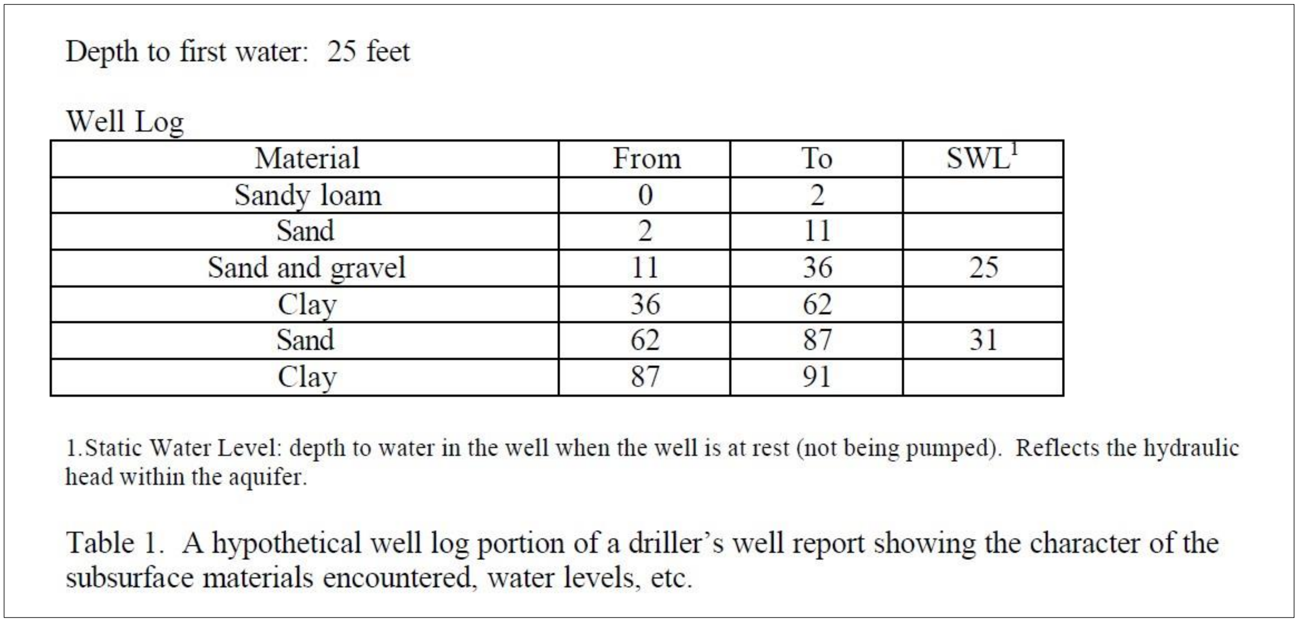
Above, several “typical” questions often asked of city officials were listed. In this section, examples of using existing data, including SWA reports, to answer those questions will be provided.

Nature of the aquifer. The answer to a “What is the potential impact?” question depends critically on the hydrogeologic setting, what land use activity is involved and what the management practices are at the facility. We will address only the hydrological aspects here, described above as the intrinsic factors determining susceptibility, i.e., nature of the aquifer, depth to the aquifer, etc.

Perhaps the most important of the intrinsic properties in this instance is the nature of the aquifer: unconfined *versus* confined. The reason for this is that confined aquifers, owing to the presence of a low-permeability layer separating the aquifer from the surface, are much less susceptible to surface activities than are unconfined aquifers.

In some cases, you may be fortunate enough to find that the area of concern is covered by an existing hydrologic or hydrogeologic report. Perhaps within that report you find that there are two aquifers in the area, an unconfined sand and gravel aquifer and a confined sand aquifer. Assuming you know in which aquifer the well of concern is (see discussion on well reports below), you can reach a first level decision regarding the susceptibility of the aquifer.

Using Well Reports. Let's say, however, that you do not know which aquifer is the source of the water, or perhaps, as is common, no hydrogeologic report exists for the area. What do you do then? Your primary source of information is the well report. Most of these intrinsic factors that we have discussed can be estimated from well reports in the area. The plural is used to emphasize that you will need to review several well reports, both because the local geology may vary and because the interpretations by the drillers will vary. To illustrate how information can be obtained from well reports, and given that different states have different report forms, we have selectively reproduced specific information from a well report (Table 1).



Depth to first water: 25 feet

Well Log

Material	From	To	SWL[1]
Sandy loam	0	2	
Sand	2	11	
Sand and gravel	11	36	25
Clay	36	62	
Sand	62	87	31
Clay	87	91	

1.Static Water Level: depth to water in the well when the well is at rest (not being pumped). Reflects the hydraulic head within the aquifer.

Table 1. A hypothetical well log portion of a driller's well report showing the character of the subsurface materials encountered, water levels, etc.

In the well log portion of the well report, the driller reports drilling through a number of layers of different materials, e.g., sand and gravel, clay, etc. The occurrence of first water is reported at a depth of 25 feet. The well log indicates that this water is within the sand and gravel layer. Further, the static water level within the sand and gravel is also 25 feet. That indicates that the groundwater at 25 feet was not under pressure other than atmospheric. The occurrence of the SWL at the same or similar depth as the first occurrence of groundwater is indicative of an unconfined aquifer. In fact, if we examine the well log, we find that there are no low permeability layers between the surface and the 25-foot level.

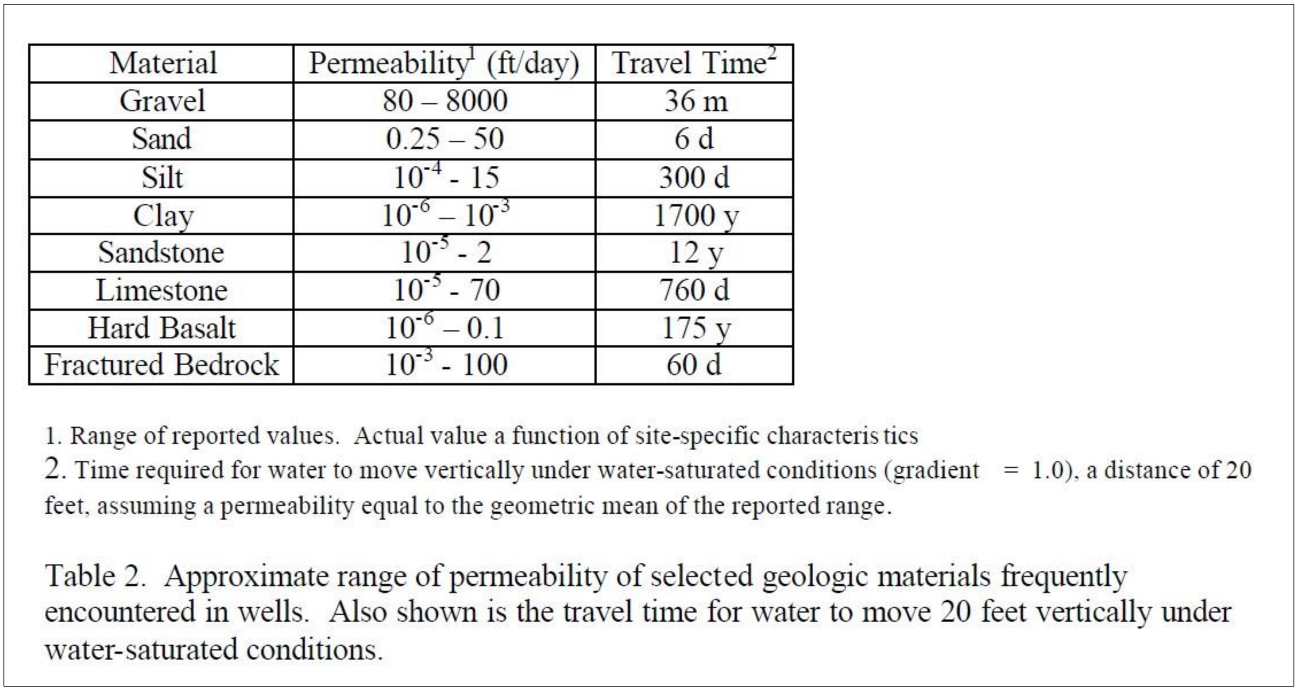
It is important to note here that “first water” to a hydrogeologist may be different from “first water” as recorded by a well driller. In the former case, we are interested in the depth at which saturation occurs. To a driller, first water may be the depth at which sufficient water occurs to meet the need of their client. Frequently this is deeper than the top of the zone of saturation. The absence of a candidate for a confining layer above the first water depth is a good indication that the static water level is actually the top of the zone of saturation, i.e., the top of the aquifer.

Below the sand and gravel, the driller went through 26 feet of clay before entering a sand unit. The SWL within the sand unit is 31 feet. In other words, when the driller punched into the sand unit, the groundwater there was under sufficient pressure to rise from a depth of 62 feet to a depth of only 31 feet. This excess pressure is an indication that the aquifer is confined. The clay layer above the sand unit is the likely confining unit. Other materials that might serve as a confining unit include mud, silt, volcanic ash, unfractured (usually described as hard) bedrock, shale, etc.

A note of clarification is important here. In most states, the above well, which appears to tap two separate aquifers, would not be legal. This mixing of aquifers, or commingling, may provide an avenue for shallow contaminants to gain access to deeper aquifers. In the current example, the water level in the shallow aquifer is higher than in the deep aquifer. If the shallow aquifer was contaminated movement of that water to the deeper aquifer would occur. Many old wells, e.g., drilled prior to 1975, were not constructed with commingling in mind. If the well report being examined is open to two or more aquifers, its potential for contamination is higher, even if the aquifer being tapped is confined.

The reason for confined aquifers being less susceptible than unconfined aquifers is clear from this well log. Contaminants from the surface would have to move down only 25 feet, through relatively permeable sand and sand and gravel to reach the upper aquifer. Contaminated water would have to travel 36 feet to the clay layer and then an additional 26 feet through the clay to reach the lower aquifer.

The ability of materials to transmit water is characterized by their permeability and can be a first estimate of how well they would retard the downward movement of water. In Table 2, the approximate permeability of common materials is listed, along with the estimated travel times through 20 vertical feet, assuming water-saturated conditions.



Material	Permeability[1] (ft/day)	Travel Time[2]
Gravel	80 – 8000	36 m
Sand	0.25 – 50	6 d
Silt	10^{-4} - 15	300 d
Clay	10^{-6} – 10^{-3}	1700 y
Sandstone	10^{-5} - 2	12 y
Limestone	10^{-5} - 70	760 d
Hard Basalt	10^{-6} – 0.1	175 y
Fractured Bedrock	10^{-3} - 100	60 d

1. Range of reported values. Actual value a function of site-specific characteristics
2. Time required for water to move vertically under water-saturated conditions (gradient = 1.0), a distance of 20 feet, assuming a permeability equal to the geometric mean of the reported range.

Table 2. Approximate range of permeability of selected geologic materials frequently encountered in wells. Also shown is the travel time for water to move 20 feet vertically under water-saturated conditions.

Although the values in the table are only approximate, it is clear that a clay confining unit significantly reduces the risk of contamination of an aquifer. The above information would allow the planner to make a first assessment of the susceptibility. Quantitative assessments would require the assistance of a professional.

If a Source Water Assessment has been performed in the area of interest, depending on the specific state's procedures, you may find that the aquifer has already been characterized and an assessment of the susceptibility of the drinking water source to contamination has been accomplished. Contact the public works office of the community or the state agency that oversees drinking water quality.

Direction of groundwater movement.

In many cases, concern regarding the potential impact of a facility on local groundwater can be addressed by determining the general direction of groundwater flow. For example, if a facility is not located where groundwater is moving from the facility towards the well, the threat is considerably less.

As described above, the driving force for groundwater movement is the hydraulic head, with groundwater moving from where the hydraulic head is greater to where it is lower. Although this is true for both unconfined and confined aquifers, it is typically easier to visualize in the former.

An unconfined aquifer can be visualized as a body whose thickness is small relative to its width and length. The top of the aquifer is the water table, and again, the term "table" implies a sheet-like geometric form. However, if we could view the water table directly, we would see that it is not a flat surface. As with the land surface, the water table has highs and lows and in a more subdued way reflects the overlying surface topography, i.e., the water table is higher under hills and lower under valleys. (Note that we cannot make the same assumption with confined aquifers)

In an unconfined aquifer, the hydraulic head (head) is reflected by the elevation of the water table at that particular spot. Therefore, if we had a representation of the shape of the water table, we would be able to estimate the direction of groundwater flow. So how can we obtain such a map? Hydraulic head or water table elevation maps are prepared by hydrologists through the measurement of the static water level in a series of wells spread out across the aquifer. It is very important to note that all these wells must be in the same and only the same aquifer. The SWLs are converted to elevation and plotted on a map. Contours (lines connecting points of equal water table elevation) are then drawn to match the data (see exercise in the *Groundwater Training Manual*). Once the head map is contoured, the direction of groundwater flow can be estimated by drawing an arrow through the contours from higher head to lower head. The arrows are constructed perpendicular to the contour lines.

As an example of how this information can be used, consider the following. A community learns of a gravel/asphalt operation that has been proposed in an area near their wells. They are concerned that the operation might impact their drinking water sources. The map below (Figure 1) illustrates the relative positions of their six wells and the gravel operation. They were particularly concerned about Well 3 because of its proximity to the proposed facility.

During the source water assessment for this community, a contoured hydraulic head for the region was obtained from a USGS publication and two of the contours are illustrated on the map (the 125- and 130-foot contours of the elevation of the water table). The community constructed approximate groundwater flow lines by drawing arrows perpendicular to the contours. This exercise indicated that groundwater flow was such that the only wells potentially affected by the gravel operation would be 1 and 2. Based on the flow paths, groundwater that supplies Wells 3 through 6 comes from the west, not the south.

This analysis was not sufficient to determine whether Wells 1 and 2 would be impacted, however, it did allow the community to focus their resources on evaluating the potential impacts on those two wells, significantly reducing the cost of the subsequent consulting study.

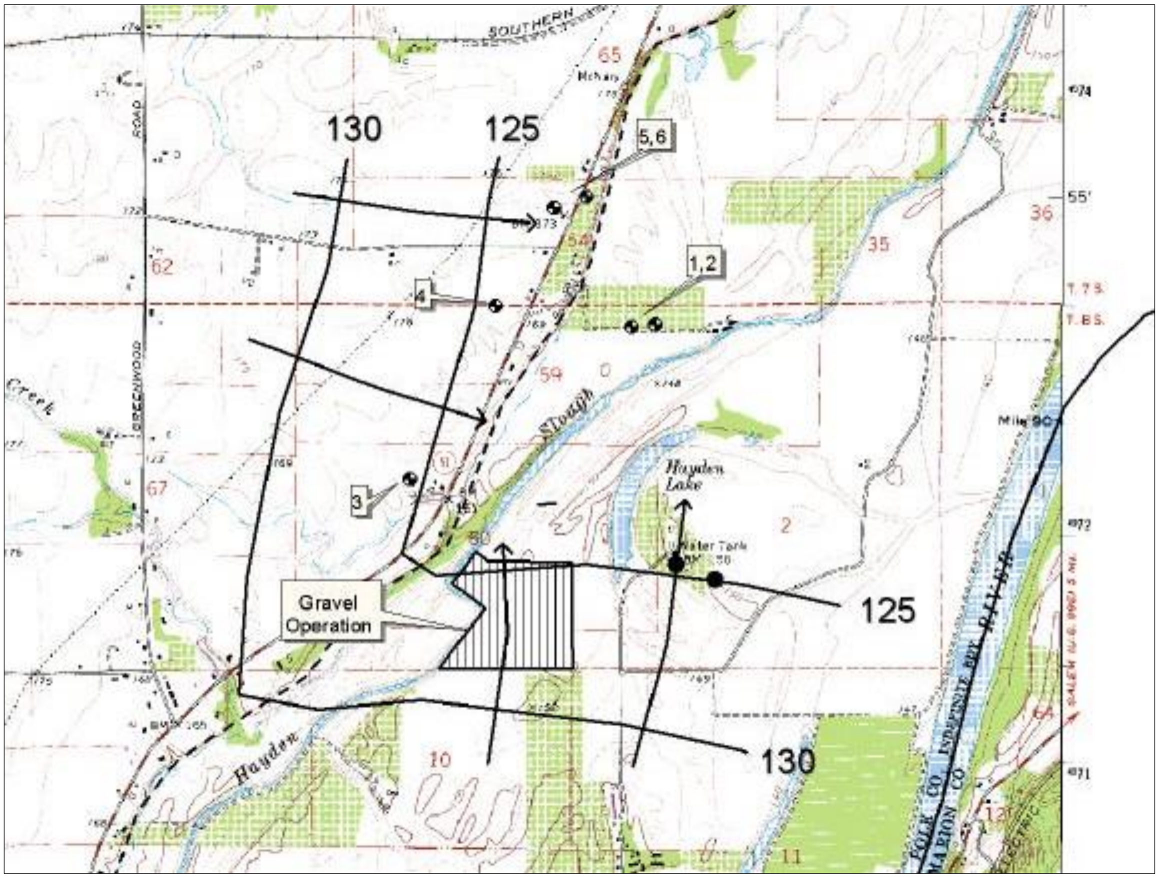


Figure 1. Map illustrating the distribution of hydraulic head in an unconfined sand and gravel aquifer. Numbered symbols represent wells in a community's wellfield. Solid lines represent contours of equal elevation of the water table (labels, e.g., 125, represent the elevation). Solid arrows estimate the groundwater flow direction. Ruled area outlines a proposed development of a gravel/asphalt operation.

Source Water Assessment

As an example of using Source Water Assessment data in a planning decision, consider the situation shown in Figure 2. This community is trying to decide where to site a new non-sewered residential development. Two potential sites are available for this development, designated as Site A and Site B in Figure 2. Local residents have expressed concern that the effluent from the septic systems might contaminate their shallow aquifer.

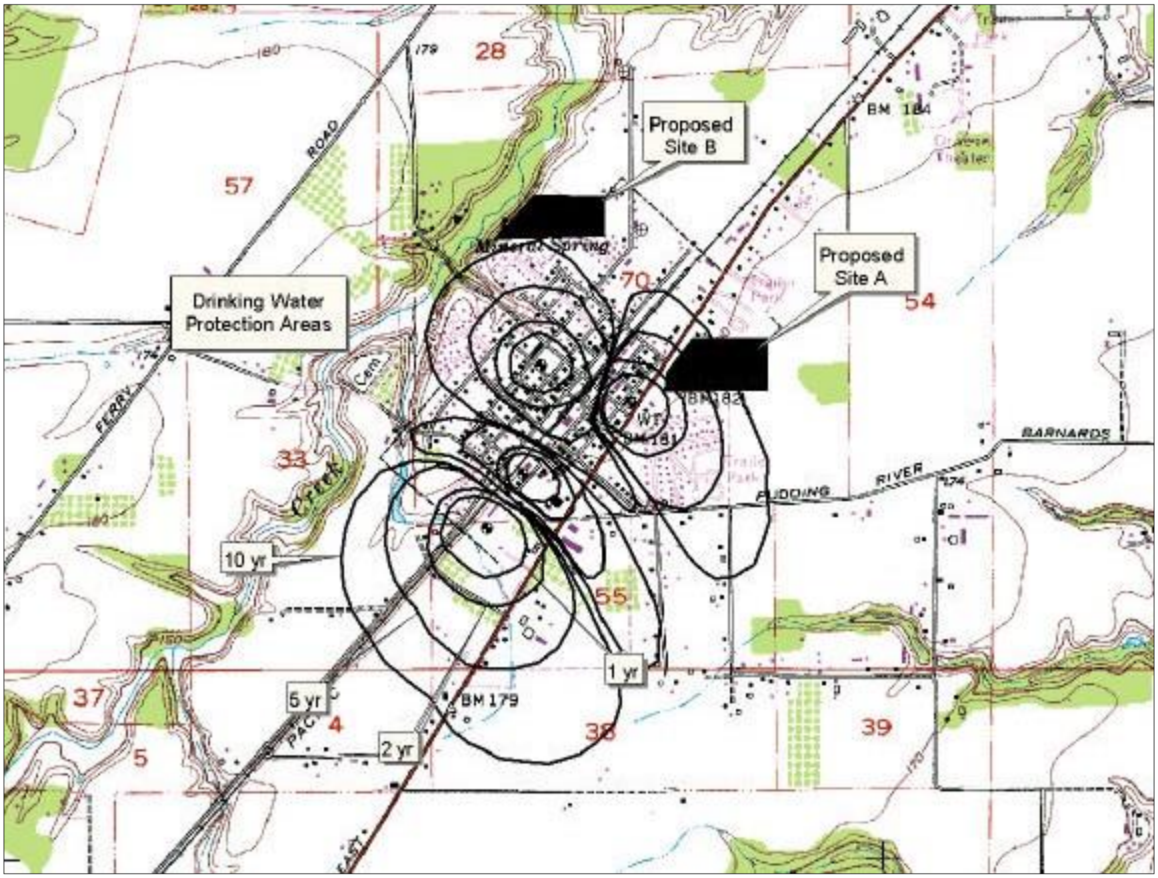


Figure 2. Map showing the drinking water protection areas for a community with the 1-, 2-, 5-, and 10-year time-of-travel of groundwater movement to the wells. Proposed Sites A and B reflect areas of potential development of non-sewered residential areas.

The City Council obtains the delineation of the community’s source water protection areas (drinking water protection areas in Figure 2). The delineation has identified the 1-, 2-, 5- and 10-year time-of-travel (TOT) for groundwater within the aquifer to move to the wells. The delineation clearly favors Site B, while falls outside the 10-year TOT, over Site A, which extends into the 1-year TOT.

The Source Water Assessment has allowed the community to make a much more informed decision, allowing continued development within their boundaries without putting their drinking water resource in significant risk.

Conclusions

Rapid growth and community development needs have placed significant challenges to communities as they try to balance the accommodation of growth with the preservation of needed resources. Safe drinking water is fundamental to the viability of any community and the cost of having to treat water because it has become contaminated is extremely high and may be a public relations issue with new business and residents.

Data are available to assist communities in making informed decisions regarding land use activities. Published hydrogeologic reports may provide important information regarding the nature of the aquifer and the occurrence and movement of groundwater in the subsurface. Well reports completed by well constructors as they drill wells are also an important source of information.

Perhaps the most useful and widespread documents that address local groundwater systems are the Source Water Assessments that are mandated of the states by the 1996 Amendments to the Safe Drinking Water Act. These assessments are designed to provide information to communities so that they might develop strategies to protect their resource. Components of the assessment include (1) the delineation or identification of the Source Water Protection Area (SWPA) that identifies that part of the aquifer that supplies water to the well or spring, (2) an inventory of potential contaminant sources within the SWPA, and (3) a determination of the susceptibility of the drinking water source to those potential contaminants.

Maps provided in the assessment report allow communities to evaluate particular sites or activities with respect to their source of drinking water. The assessments provide an important tool to assist communities in present and future land use decisions.

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