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AQUIFER YIELD MAP OF OHIO

by
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INTRODUCTION

Aquifer yield quantifies the volume of groundwater that is dischargeable from an aquifer per unit time via either pumping or natural flow. It is a function of both the physical properties of the aquifer media, such as its saturated thickness, hydraulic conductivity, and storativity, and the physical properties of the well, including its construction, development, and intended use. In this map, aquifer yield is represented as a range of pumping rates, in units of gallons per minute (gpm), which can be anticipated for a well in a given aquifer under historically normal hydrologic and climatic conditions.

This map builds upon previous hydrogeologic publications by incorporating new data and establishing new standards that allow for higher-resolution, seamless, methodologically consistent mapping of aquifer yield across Ohio. It can be used to assist well drillers, homeowners, municipalities, industries, and agricultural users in quickly estimating the expected yields of the aquifer(s) in their area of interest.

BACKGROUND INFORMATION

The Ohio Department of Natural Resources (ODNR) has a long history of mapping Ohio's aquifers and their yields. As early as the 1940s, ODNR geologists were collaborating with the U.S. Geological Survey (USGS). The Ohio State University, and other institutions on the mapping and cataloging of groundwater at the city or county scale. The Ohio Water Resources Board published the State's first water bulletin to include detailed information on both groundwater and surface water in 1946, *The Water Resources of Fayette County, Ohio* (Bernhagen and others, 1946). The ODNR Division of Water (ODNR-DW) published its first bulletin, *The Water Resources of Greene County, Ohio*, in 1956 (Norris and others, 1950). These publications are precursors to the first standalone groundwater resources map (GWR), *Ground Water Resources of Columbiana County*, which was published in 1978 (Crowell, 1978). The GWR series of publications provides useful information on Ohio's aquifer types, expected well yields, and expected well depths. However, their county-by-county approach and the extended intervals of time between their releases resulted in discrepancies in their respective methodologies, boundaries, and symbology.

In 1996, the ODNR-DW initiated the Statewide Aquifer Mapping Program to standardize naming conventions and delineate aquifers at a 1:24,000 scale (ODNR, 2000a, 2000b). Aquifer-yield ranges of unconsolidated aquifers spanned from 0–5 to 500+ gpm, while ranges for consolidated aquifers spanned from 0–5 to 100+ gpm. These maps became some of the earliest ODNR publications to provide statewide aquifer coverage using Geographic Information Systems. In 2022, the ODNR Division of Geological Survey (ODNR-DGS) completed work on the Groundwater Vulnerability GIV map (Nelson and others, 2022). Though not a yield map, ODNR-DGS geologists mapped hydrogeologic characteristics such as aquifer rating and hydraulic conductivity that can be used to assess the relative yield of Ohio's aquifers.

To address some of the limitations of the previous maps, provide increased spatial resolution, and incorporate new data at a statewide scale, the ODNR-DGS began work on this product in 2022 with funding from the Ohio Water Development Authority (OWDA). Mapping concluded in late 2024, and the result is the new statewide, seamless *Aquifer Yield Map of Ohio* shown here.

MAPPING METHODOLOGY

Prior to the start of mapping, available water-well data underwent a data preparation phase to ensure accuracy of the information. Approximately 40,000 water wells with completion test rates greater than 50 gpm were edited to correct their locations and attributes. Over 67,000 previously unlocated wells were assigned coordinates via geocoding. An additional number of wells were manually located, though this was performed only for wells with completion test rates greater than 60 gpm to ensure the project was completed within the requisite time.

To ensure a consistent schema across the entire state, aquifer yield was represented in this map with nine distinct ranges spanning from 0–3 to 1,000+ gpm (table 1). Mapping was performed at a 1:10,000 scale. Initial aquifer boundaries were delineated based on the hydrogeologic settings, aquifer media, and aquifer ratings parameters of the GV map (Nelson and others, 2022). Lines were then added, modified, or deleted based upon the methodology described below. Aquifer types were also refined from the GV map to include well-known, mappable units (e.g., Columbus Limestone) and lithologic and hydrogeologic units distinguished by age (e.g., Pennsylvanian-age sandstones).

Yield data also were compiled from pumping tests, slug tests, digitized and georeferenced GWR maps, environmental consultant reports, USGS publications, and published scientific papers. Literature values from publications such as Schumacher and others (2013), georeferenced regional studies (Walker and others, 1965; Rau, 1969; ODNR 1970, 1972; Ohio Drilling Company, 1971, 1973; Sedam, 1973; Buglioni, 1999), and previously published ODNR maps (ODNR, 2000a, 2000b) provided additional information on aquifers and their expected yields.

Pumping-test reports were considered the most accurate data source for yield estimates and were utilized whenever available. High-capacity production well completion-test data were also relied upon, though they were given less weight than pumping-test reports, especially if their reported yield values were contradictory. If no high-confidence data were available in an area, these high-yielding wells were often the best available approximation of aquifer yield. However, their distribution across the state is not uniform and they tend to be spatially constrained within high-yielding aquifers.

Completion-test rates and sustainable yield values of lower-capacity wells provided the largest quantity and spatial distribution of yield data but were also the most inconsistent (ODNR, n.d.). Common errors within the Ohio water well log dataset include filing, transcribing, and digitization errors, which are time-consuming to correct at a statewide scale. Reported sustainable yields and completion-test rates often underestimated expected yield for a given aquifer when compared to other data sources. This was attributable to the well use, construction, or completed depth relative to the water table. The bulk of these lower-producing wells were domestic wells with relatively small-diameter casings, shallow completion depths, low-capacity pumps, and/or screens that may only partially penetrate the aquifer. To account for the systemic underrepresentation of test rate and sustainable yields within these lower-capacity wells, well data were weighted against other data sets and publications. If no high-confidence data such as pumping tests were available in an area, the initial yield ranges were determined using literature values, and the low-capacity water well point-source data were used to establish further trends.

Yield was mapped for both the primary and secondary aquifers throughout the state. A primary aquifer was defined as the more-utilized, higher-yielding aquifer unless some consideration(s) such as its depth or its groundwater quality disqualified it for most uses. A secondary aquifer was defined as the lower-yielding or alternate aquifer that may be suitable for some uses. In areas where multiple aquifers were present, the relative number of wells completed in each aquifer were weighed when making primary and secondary aquifer designations. Distinctions first were made between unconsolidated and consolidated aquifers using the well log aquifer type, as well as previous GWR maps that show the extents of unconsolidated units. The aquifer type also was used to distinguish between consolidated aquifers where the aquifer lithology was dissimilar. When consolidated lithology was the same (e.g., two limestone units), other resources were used, including bedrock geology maps, structure contours, bedrock descriptions of the top of units, and measured sections. To distinguish multiple unconsolidated units, water well log total depths, GV aquifer media, and Quaternary geology maps were used. The digital dataset included the reason(s) an aquifer was denoted as secondary.

In certain situations, when more than two viable aquifers were present, such as an area with two consolidated limestone aquifers and one unconsolidated sand-and-gravel aquifer, mappers often erred towards including the dissimilar aquifer. This method preserved more of the unique hydrogeologic setting of the area than if only the two similar aquifers were chosen. However, in some situations, for example in areas where the identifiable aquifers were Silurian-age limestone, Columbus Limestone, and Devonian-age shale, the relative number of wells and the relative yield of the aquifer was given more consideration than the similarity of the aquifer type. In these areas, the limestones usually had higher yields and, if the relative number of wells for each aquifer was the same, the limestone designations were preserved over the shale. In some cases, the lithologies, yields, and relative number of wells were the same for multiple aquifers. For example, the Logan and Cuyahoga Formations in Knox County were mapped as a sandstone-dominant aquifer (Logan), a shale-dominant aquifer (Cuyahoga), and an interbedded aquifer (Logan and Cuyahoga), with the Black Hand Sandstone Member of the Cuyahoga Formation also being split out in certain areas. In such cases, structure contours for the tops of the units were used in conjunction with water well log depths and a digital elevation model (OGRIP, 2006) to determine the relative aquifer usage.

When present, notable consolidated aquifers such as the Black Hand Sandstone and the Berea Sandstone were delineated because of their high-yielding properties and relatively high use compared to other nearby units. In the case of the Berea Sandstone, this unit was represented in two aquifer types, the former indicating that the Berea was the dominant lithology and the latter describing areas where Berea was utilized alongside or indistinguishably from the less-productive Sunbury and Bedford Shales. The Black Hand Sandstone was given a similar treatment where it was split from the Logan and Cuyahoga interbedded aquifers in certain areas.

Buried valleys were delineated utilizing water well logs, GWR maps, the GV map, and a variety of bedrock topography data, including modified published and unpublished map data from the ODNR (Brockman and others, 2003; Nelson and others, 2022; Norris and others, 2024; Norris, T.A. and others, unpublished data, 2024; ODNR, n.d.). In some areas, such as the Teays Valley in Champaign County, buried valleys were stereplotted with respect to previous publications following updates to bedrock topography data (Norris and others, 2024). In some areas, glacial complex or outwash aquifers were present overlying a buried valley, but no secondary aquifer was mapped because the aquifer lithologies were similar and the buried valley was more productive. Where bedrock underlying the buried valley was deep, the buried valley was mapped as the sole aquifer; but in areas where underlying bedrock was shallow and where there was an appreciable number of bedrock wells, secondary bedrock aquifers were assigned.

Other Surficial Deposits (OSD) was another unique aquifer type. These were defined as any surficial features which did not match the definition of alluvial or glacial deposits but are still used as aquifers. One example of this was along the preglacial valley feature present in Ross, Pike, and Scioto Counties. The deposits here are silts, sands, and weathered shales which have distinctly lower yields when compared to more traditional buried-valley deposits. In other cases, OSD were delineated where there were thick surficial deposits of muck, mud, silt, or wetland deposits.

Other hydrologic features like surface water bodies also had to be considered. Streams and rivers overlying aquifers act as important areas of groundwater recharge or discharge. In areas where rivers were of sufficient size and/or connection to the aquifer to induce recharge, aquifer yields were often raised to account for their presence, especially in areas where shallow or surficial aquifers would be more highly influenced by induced recharge than deeper or less hydrologically connected aquifers. Tributaries of larger rivers and streams often were assigned a slightly lower yield relative to the main channel of the river to account for the decrease in stream size and order.

DISCUSSION

This map serves as an update to many previous ODNR publications, including the GWR maps and the consolidated and unconsolidated aquifer maps produced from the Statewide Aquifer Mapping Program (ODNR, 2000a, 2000b). It will provide users with statewide, seamless, and methodologically consistent aquifer yield information at a high spatial resolution. The inconsistencies previously observed with the GWR maps, such as their discrepancies in aquifer continuity and yield from county to county, have been ameliorated by implementing the standards and practices described above. Aberrations present on previous publications, such as localized anomalies of high yield, have been largely removed, and new data have been incorporated to allow for the determination of more accurate yield ranges.

The availability of new data, absent at the time of previous publications, was perhaps the single most valuable asset for the advances of this map. Since the final publication in the GWR map series in 1996, over 225,000 new water wells have been added to the Ohio Water Well Database (ODNR, n.d.). These new wells provided more spatial coverage of yield across the state and new insight to yield ranges within aquifers. Additionally, new pumping-test information from consultants, the USGS, and ODNR water well logs were included, which provided even more information regarding aquifer yield potentials across the state. New mapping standards have also allowed for more refined yield mapping than in the past. Many of the previous ODNR aquifer maps, such as those produced from the Statewide Aquifer Mapping Program (ODNR, 2000a, 2000b), were created at a 1:24,000 scale, while this map was produced at a 1:10,000 scale. This finer scale allowed for greater detail in drawing lines for primary aquifers, secondary aquifers, and aquifer yields.

While these new data provide more up-to-date information regarding yield, map users still should follow the subsequent considerations. As a living dataset, the Ohio Water Well Database is constantly updated with new well data; therefore, it is possible that yields depicted on this map will not always reflect data acquired subsequently to the map's publication. If this map or its underlying data are incorporated into a formal report, thesis, or publication, it is recommended that its version and date accessed be included as part of the citation or reference. Additionally, there was a high degree of variability within and between most datasets, so individual, measured well yields may not always match an area's mapped yield. To mitigate this, yield ranges were used so that each mapped area includes a spectrum of possible well yields. These ranges were more granular than those of previous publications because of the increased availability of data.

The *Aquifer Yield Map of Ohio* has a wide range of uses, particularly for drillers, municipalities, homeowners, industrial users, and agricultural users. This product provides information regarding the size, shape, and yield of primary and secondary aquifers throughout the state of Ohio. It also facilitates assessment of groundwater availability, locations of productive water-bearing units, and areas where water resources are limited. Areas where higher yields have been mapped based on available yield data will provide quick and intuitive guides on well locations, while the information on aquifer position will also enable users to target either upper or lower aquifers depending on their needs and resources. This map can be used effectively in conjunction with other datasets, such as the Ohio Water Well Database or geotechnical reports, to make a preliminary assessment of yield at a given site and inform decisions on the need for site-specific test drilling or targeted hydrogeologic assessment.

The expected representative well use(s) for each mapped yield range are provided (table 1). Users can cross-reference the map and table to determine what use(s) are appropriate for their area of interest or, conversely, evaluate whether the aquifer at a given location can sustain an intended use. If, for example, an irrigator would like to install a center-pivot irrigation system on a property in an area mapped as yielding only 50–100 gpm, then caution should be taken that the intended withdrawal not exceed the aquifer's productive capacity. If that same area were mapped as yielding 1,000+ gpm, then the user could be more assured that the aquifer should be able to sustain their intended use, though field confirmation may still be necessary. Higher-yield ranges also imply the suitability of well uses represented by lower ranges (e.g., an area mapped in the 25–50 gpm range, which supports large domestic use, small businesses, trailer parks, and small-scale farming, would also be suitable to support domestic wells [10–25 gpm], small domestic wells [3–10 gpm], and gardening [0–3 gpm]). Users of the map should be careful in relying too categorically on the suggested or implied uses, as their true suitability in an area may depend on multiple factors and true aquifer yields may differ from the mapped ranges, especially in areas with less available and/or conflicting data.

Regional and subregional trends in aquifer yield can be observed in the statewide maps to the right. Figures 1–3 display how primary yield has been mapped for three unique hydrogeologic regions of Ohio following the methodology and considerations described above. These insets allow for distinctions in aquifer type and configuration to be observed in the changes to primary yield. Users of the digital dataset will be able to view the statewide map at custom scales and access other mapped parameters to build a more complete understanding of the aquifer(s) in their area of interest.

Finally, it is important to note that this map was produced to reflect the expected aquifer yields of Ohio under historically normal hydrologic and climatic conditions. The effects of prolonged drought, elevated recharge, or other short- or long-term climatic factors may render its estimates inaccurate under conditions outside the historical norm. To fully assess an aquifer's capacity, this map must be used in conjunction with groundwater-level data to ensure the volume of groundwater available in the aquifer is sufficient for the intended use. In some cases, aquifer hydrogeology may be suitable to provide the yields mapped here, but significant local or regional groundwater depletion may reduce an aquifer's effective yield. Pre-existing withdrawals were not subtracted from the mapped yield ranges, meaning the mapped yield may already be partially or fully accounted for by existing users. Users of this map must carefully consider the magnitude of existing withdrawals when estimating the expected yield of an area of interest.

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DISCLAIMER

This product of the Ohio Department of Natural Resources (ODNR), Division of Geological Survey is intended to provide general information only and should not be used for any other purposes. It is not intended for resale or to replace site-specific investigations. These data were compiled by the ODNR Division of Geological Survey, which reserves the publication rights to this material. If these data are used in the compilation of other data sets or maps for distribution or publication, the source must be referenced.

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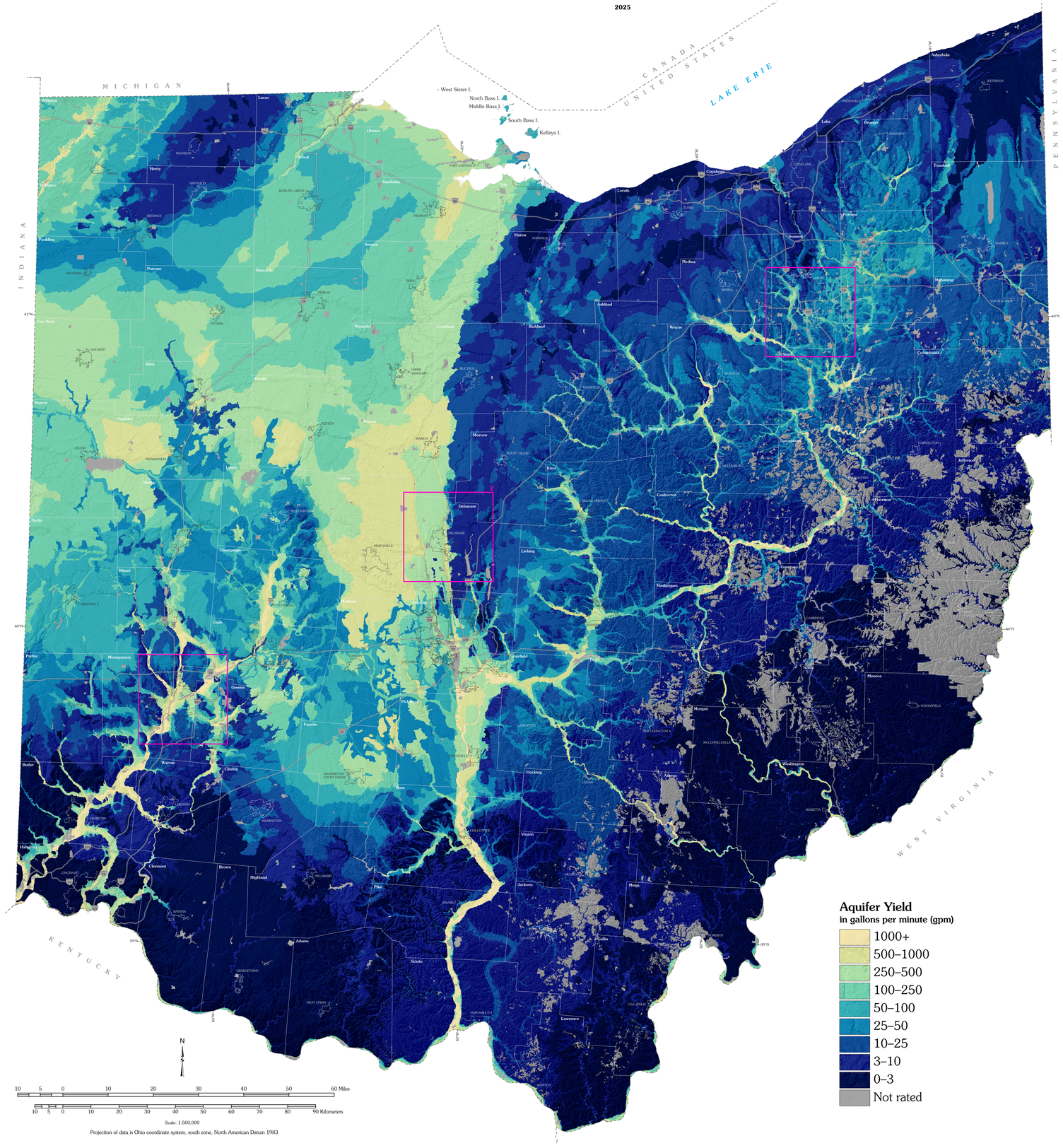

UNDERSTANDING AQUIFER YIELD

Hydraulic Conductivity

Aquifer yield can be more precisely conceptualized as the maximum rate of groundwater withdrawal sustainable in an aquifer at a location without causing an unacceptable decline in its hydraulic head, i.e., the potential energy of the water represented as a height above a datum (Hubbert, 1940; Freeze and Cherry, 1979). It predicts a threshold at which higher pumping rates would be expected to significantly impact groundwater levels, though quantifying the level of impact that qualifies as "significant" is difficult, and the effects of well interference mean impacts will be highly dependent on the number and spacing of wells in a given area. To better understand how yield has been estimated for this map, a simplified study of aquifer and well hydraulics is necessary.

When an aquifer is pumped, the decline in its hydraulic head propagates outward from the well bore as a low-pressure area develops and groundwater migrates from the aquifer to replace the withdrawal (Driscoll, 1986). This process forms a cone of depression, which is a steepening slope in hydraulic head. The morphology of the cone is a function of both the aquifer's properties and the well's construction, pumping rate, and pumping duration. The drawdown, or magnitude of the decline in hydraulic head, is measured as the difference between the pre-pumping static water level and the pumping water level (fig. 4).

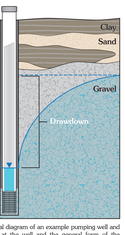

FIGURE 4. Conceptual cross-sectional diagram of an example pumping well and its aquifer, showing the drawdown at the well and the general form of the resultant cone of depression.

As the aquifer is further pumped, the cone of depression may continue to expand until it reaches a hydrogeologic boundary or it stabilizes as an equilibrium is established between the withdrawal and the aquifer's recharge. Changes to recharge or boundary conditions will affect the cone, and changes to its morphology will be mediated by the aquifer hydrogeology. The mechanics by which groundwater is actually released from the formations of an aquifer are therefore important in understanding how aquifer yield is defined at different locations and between aquifer types. In confined aquifers—those bounded from above and below by impervious formations and where hydraulic pressure drives the hydraulic head above the bottom of the upper bounding surface—pumping releases water from the aquifer via the decompression of the formation's solid matrix and, to a much lesser extent, the water itself. In unconfined aquifers—those not bounded from above by an impervious formation and where hydraulic pressure at the top of the saturated zone is equal to atmospheric pressure—water is gradually released from the pore spaces of the aquifer as the water table lowers (fig. 5).

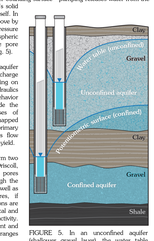

FIGURE 5. In an unconfined aquifer (shallower gravel layer), the water table forms a free surface equaling atmospheric pressure, whereas in a confined aquifer (deeper gravel layer), confining pressure drives the surface of groundwater potential above the top of the aquifer.

These definitions establish the basis for how an aquifer supplies groundwater to a well or other discharge point, as well as the expected effects of pumping on water levels. A more in-depth study of well hydraulics and other aquifer configurations (including the behavior of semiconfined or "leaky" aquifers) is outside the scope of this publication. For the purposes of understanding aquifer yield and how it was mapped here, it will suffice to explore in more detail the primary functions of an aquifer and how an aquifer's flow characteristics may be estimated to determine its yield.

In a groundwater supply context, aquifers perform two primary functions: as storage and as conduits (Driscoll, 1986). Aquifers store groundwater within their pores and interstices and conduct groundwater through the interconnections between these storage sites, as well as through joints, cavernes, and solution features, if present. The parameters governing these functions are numerous, but two in particular are both empirically and often correlative: storativity and hydraulic conductivity. Combined with information on an aquifer's extent and thickness, they can be used to estimate the yield ranges mapped here.

Aquifer Storage

Storativity (**S**), also known as the storage coefficient, defines the volume of water released from an aquifer's storage per unit decline in its hydraulic head (Bear, 1972). It summarizes the aquifer's capacity for water and is comprised of specific storage (S_s) and specific yield (S_y) components, as shown in Equation 1:

$$S = S_s b + S_y \qquad (1)$$

With all other parameters kept equal, an aquifer with a high storativity will produce more yield per unit decline in its hydraulic head, and an aquifer with a greater saturated thickness (**b**) will have more available head to draw down. The storativity of a confined aquifer can be calculated using specific storage and saturated thickness, while the storativity of an unconfined aquifer is usually approximated as being equal to its specific yield because the compressibility of the water and the solid matrix can be considered negligible (Kruseman and de Ridder, 1991). One notable characteristic of specific yield is that it is a time-dependent quantity; the release of stored groundwater as an unconfined water table lowers is a gradual one, though use of the term often assumes sufficient time has passed for the drainage to be complete (Bear, 1972; Fetter, 2018).

Being a measurement of a volume per unit length decline per unit area, storativity is dimensionless. It accounts differentially for isolated voids and dead-end pores, though its constituents (specific storage and specific yield) must consider these as well. In the case of specific yield, the volume of water retained in the aquifer is now by conflict quantity; the release of stored groundwater as an unconfined water table lowers is a gradual one, though use of the term often assumes sufficient time has passed for the drainage to be complete (Bear, 1972; Fetter, 2018).

Aquifer Transmissivity

Being a measurement of a volume per unit length decline per unit area, storativity is dimensionless. It accounts differentially for isolated voids and dead-end pores, though its constituents (specific storage and specific yield) must consider these as well. In the case of specific yield, the volume of water retained in the aquifer is now by conflict quantity; the release of stored groundwater as an unconfined water table lowers is a gradual one, though use of the term often assumes sufficient time has passed for the drainage to be complete (Bear, 1972; Fetter, 2018).