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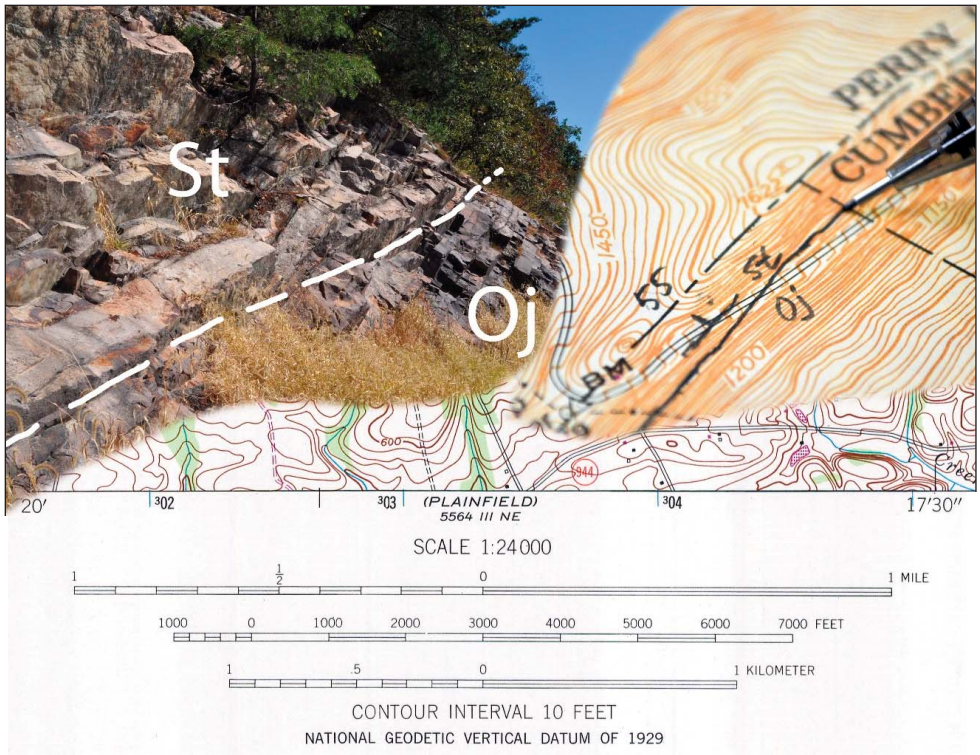

To geologists, geology and mapping are inescapably tied together. Geologists take what they observe in the field, interpret a 3-dimensional model, and try to convey that model on a 2-dimensional plane in such a way that others will see what they see. Depicting a real-world model on a map is only a matter of scale. Or is it? (See article on page 3.)

EDITORIAL

Hey! Take the Rest of the Day Off!

Gale C. Blackmer, State Geologist
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It used to be a mystery to me how the director could come up with an idea for a column for every issue of *Pennsylvania Geology.* Now I believe I know the secret: sometimes in the press of work and life, the creative well runs dry. Anne Lutz, our wonderful volunteer editor, sent an email to me more than a week ago asking for the column. That email was promptly buried in my inbox, while thoughts of the column were buried by more than the usual onslaught of administrative demands. So it was that I found myself on a Saturday morning, sitting at my kitchen table with a cup of coffee and a draft of this issue, wondering what to write. I looked out over my backyard, constantly distracted by a pair of hummingbirds fighting over the black-and-blue salvia, goldfinches on the coneflowers, and the misplaced vegetation that had faded to ignorable when the weather was hot and dry but was tall and lush and calling out to be removed now that it is hot and moist.

I tried looking for inspiration from the articles in this issue: maybe something about the unique ways that geologists visualize the world using maps and data? Hmm . . . nothing there this time. Then I tried thinking of some the things we've been working on at the bureau this summer: mapping and drilling projects in Wayne and McKean Counties; the launch of EDWIN, the new version of our oil and gas well database; much discussion of climate change in the department; and moving our field guides and "touristy" publications into a new series called *Trail of Geology,* which we hope to have ready by the next issue of *Pennsylvania Geology.* All are inspirational to me as a geologist, a user of geologic data, and a bureau director, but not to the writer in me.

Then came the "ah-ha" moment. The well isn't dry; I just need to turn off the pump and give it some time to recover. After all, it's summer! What I need—what we all need—is some fun and relaxation. To borrow a signature saying from the inimitable Bill Kochanov, "Hey! Take the rest of the day off!"

Gale C. Blackmer

A Matter of Scale . . .

Thomas G. Whitfield
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What is Scale?

Did you ever think about scale (see cover)? Most people think it has something to do with measurement, but what exactly does it mean? Webster's II College Dictionary (Severynse, 1995, p. 984) has a definition of scale as follows:

> **"2.a. The proportion used in determining the relationship of a representation to that which it represents."**

Maps have a scale. Some maps have a ratio illustrating relative proportion, others have a calibrated line, and some have both. But what is a map? A map is a graphic representation of reality for you to interpret in your mind (Monmonier, 1993). It is how your mind draws a picture of Earth's surface based on what you see on a piece of paper. It is a "scaled" portion of Earth's surface as seen from above (U.S. Department of the Army, 2005).

Most people think of scale as a measure of distance. On Pennsylvania's Tourism and Transportation Map, a free road map published by the Pennsylvania Department of Transportation (PennDOT) (Pennsylvania Department of Transportation, 2016), 1 inch represents approximately 8 miles. On the map, it is 24 inches from Harrisburg to Grandma's house in Pittsburgh, which represents about 192 miles. Allowing for north-south variations as we travel east to west, Dad's odometer reads 198 miles when we get there, which is about right, given the scale of this map.

Scale, however, is much more than just distance; it also represents dimension. The relative size of objects represented on a map is just as important as where they are placed. Ridges on a topographic map, for example, must accurately represent where the ridges really are, how high they are, their extent, and how they relate to surrounding features (Figure 1).

Everyone equates scale with mapmaking, but there are other factors beyond scale that contribute to the complexity of accurate mapmaking. Cartography is both the art and the science of making a map such as the one in Figure 1. In addition to relaying the sense of scale, effective mapmaking requires an understanding of other factors such as accuracy and precision. We will explore how cartographers balance scale, accuracy, and precision to graphically capture and represent the spatial structure of both natural and man-made features of Earth on a 2-dimensional surface (Robinson and others, 1995). The cartographer's challenge is to always make a map without distorting what the map has to say (Tufte, 2001). Most of the map examples in this paper have been slightly reduced in size (and thus, their scales have been reduced) so that they will fit within the alloted space.

Finally, we will discuss how advances in technology such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) have revolutionized cartography, geography, and how we visualize things. Unfortunately, these same technologies are blurring the lines between scale, accuracy, and precision, sometimes to the detriment of the unaware user.

Location, Dimension, Distance, and Earth

We know that the shape of Earth is an oblate spheroid, a slightly flattened sphere where the diameter at the equator is greater than the diameter through the poles (Carter and others, 2005; Environmental

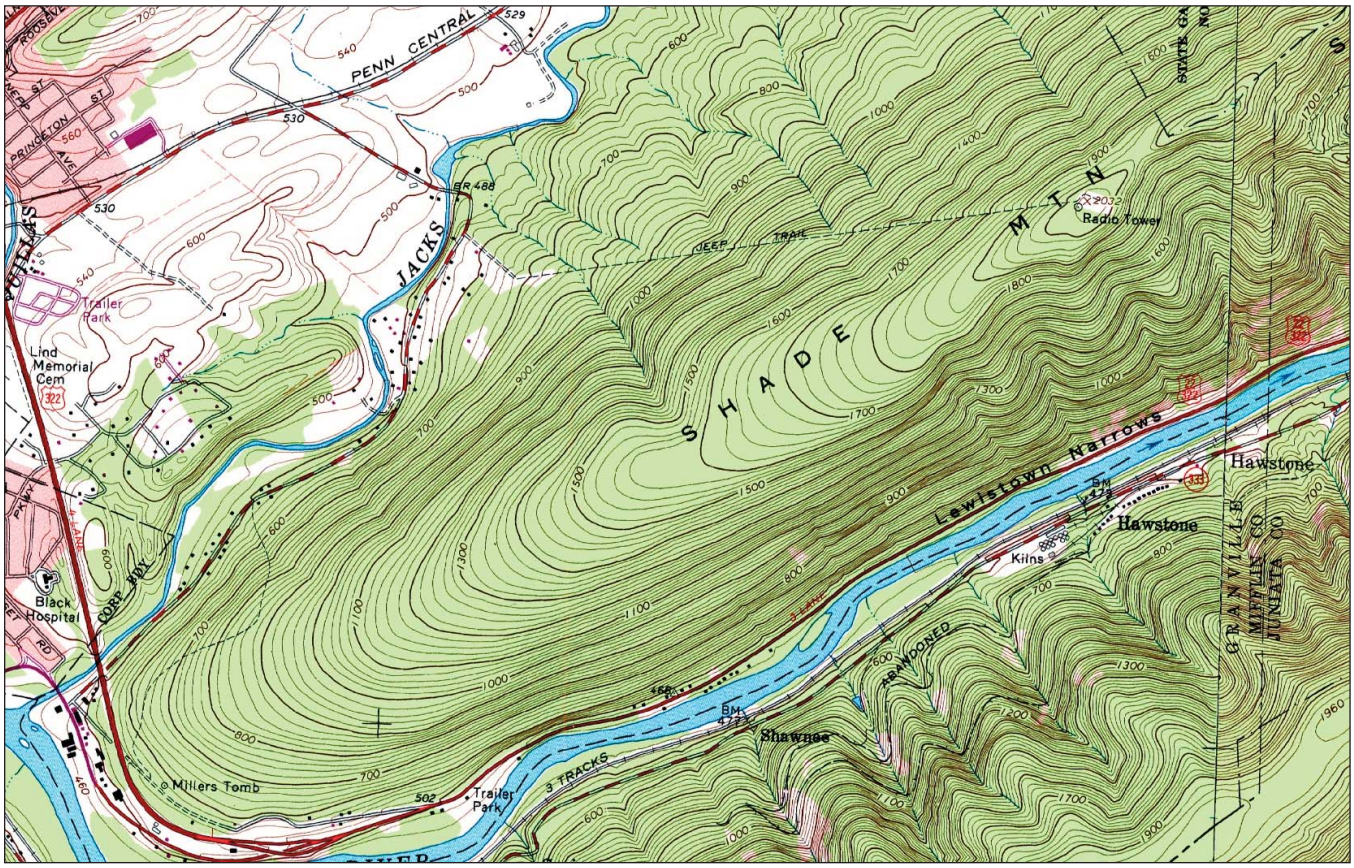

Figure 1. This is a topographic map (slightly reduced from 1:24,000) of Shade Mountain and the Lewistown Narrows in Mifflin and Juniata Counties. You can visualize the high ridge and narrow valley as you interpret the contour lines on this flat map.

Systems Research Institute, Inc., 1994). Earth has a rough surface (relief); however, it is not as rough as we might think. Using scale as a dimension, think of Earth as a standard 8.59-inch-diameter bowling ball. Mount Everest would be a mere 0.006 inch tall, and the Mariana Trench would be 0.0074 inch deep (Robinson and others, 1995). In fact, the difference between the top of Mount Everest and the bottom of the Mariana Trench is approximately 0.0134 inch. By comparison, a typical sheet of 20-pound copier paper is about 0.0038 inch thick, so this extreme difference is about the thickness of 3.5 sheets of copier paper. Mount Davis, the highest point in Pennsylvania, would be a measly 0.00066 inch tall. At the scale of a bowling ball, Earth would appear very smooth, in contrast to what we Earthlings observe at "real scale." And yes, Kansas is indeed flatter than a pancake (Fonstad and others, 2003).

Locating yourself and trying to measure distances on Earth has not always been easy. The use of latitude and longitude is an ancient way of representing your position as a point on the earth's surface and can be traced back to Hipparchus of Rhodes in the second century B.C.E. (Robinson and others, 1995). To figure distances between points on the earth's surface, one must use angular math or great circle calculations (Robinson and others, 1995). Rolling a ruler on a globe just won't work.

> **Helpful geography hint: Latitude is a north-south angular position from the equator, while longitude is an east-west angular position from the prime meridian (Robinson and others 1995; Monmonier, 1996).**

Depicting features on a globe is the most accurate way of displaying locations and distances. While working with a globe is highly impractical, stripping the paper off and flattening it out won't work very

well, either. The solution is to recast the map using a "projection." A projection is a mathematical way of depicting a curved, three-dimensional (3-D) surface on a flat, two-dimensional (2-D) plane. Most projections are based on a particular datum (a geodetic reference approximation of the earth spheroid), such as North American Datum 1927 (NAD27) or North American Datum 1983 (NAD83), and linear unit (Environmental Systems Research Institute, Inc., 1994; Monmonier, 1996; Robinson and others, 1995). There are literally hundreds of map projections in use today; all impose some form of distortion relative to the curved surface they represent. Some distort shape while preserving distance; others do the opposite (Environmental Systems Research Institute, Inc., 1994; Monmonier, 1996; Robinson and others, 1995). In other words, distortion is always part of any 2-D map representation. Although a latitude and longitude coordinate grid is commonly shown on a flat map, distance and direction are a function of the map's projection (Environmental Systems Research Institute, Inc., 1994).

Scale on Topographic and Other Maps

To geologists and other earth science enthusiasts, one of the most commonly used type of base map is the U.S. Geological Survey's (USGS) 7.5-minute 1:24,000-scale topographic map, such as the one shown in Figure 1. It is easy to handle, read, and understand. In Pennsylvania, the USGS 7.5-minute topographic paper maps are cast on a Lambert Conformal Conic projection (Environmental Systems Research Institute, Inc., 1994), and scanned versions of these same maps, called Digital Raster Graphic (DRG) files, are now cast on a Universal Transverse Mercator (UTM) projection. Symbols, colors, legends, and the like may vary slightly from map iteration to map iteration. But the scale remains the same—1:24,000—where 1 unit on the map equals 24,000 units on the ground (1 inch equals 24,000 inches, or 2,000 feet). Map scale not only applies to distance, it also applies to dimension. To illustrate scale as a dimension, consider the following statement: "A standard 0.5-millimeter (mm) mechanical pencil draws a line on a 1:24,000-scale topographic map that is nearly 40 feet wide on the ground." Here are the corresponding mathematical equations:

$$0.5 \text{ mm} \times 24{,}000 = 12{,}000 \text{ mm}$$

$$12{,}000 \text{ mm} \div 1{,}000 = 12 \text{ m}$$

$$12 \text{ m} \times (3.28 \text{ ft})/(1 \text{ m}) = \mathit{39.36\ ft}$$

To clarify this, let's talk football. The object of this game is to move an oblong ball down a playing field (or grid) in 10-yard (30-foot) increments to try to score points. A football field is a great illustration of a grid with dimension. It is 100 yards long, with 10 yards added at each end zone (for a total of 360 feet), and 53.5 yards (160 feet) wide. A 0.5-mm mechanical pencil at 1:24,000 scale draws a line just shy of 40 feet wide on the ground, or just over 13 yards wide on a football field (Figure 2).

The paper Geologic Map of Pennsylvania (Berg and others, 1980) has a smaller scale of 1:250,000. A 0.5-mm pencil line drawn at this scale equates to 136.67 yards (409.99 feet) wide. That pencil line is now wider than the entire football field, including both end zones plus another 8.5 yards beyond the goal posts on both ends. Zooming farther out to another popular map scale of 1:500,000, the line is now 273.33 yards (820 feet) wide (Figure 3).

Helpful map scale hint: To understand the difference between small-scale maps and large-scale maps, think of the scale ratio as a fraction. For example:

1:24,000 or 1/24,000 is a larger fraction than

1:100,000 or 1/100,000, which is larger than 1:250,000 or 1/250,000

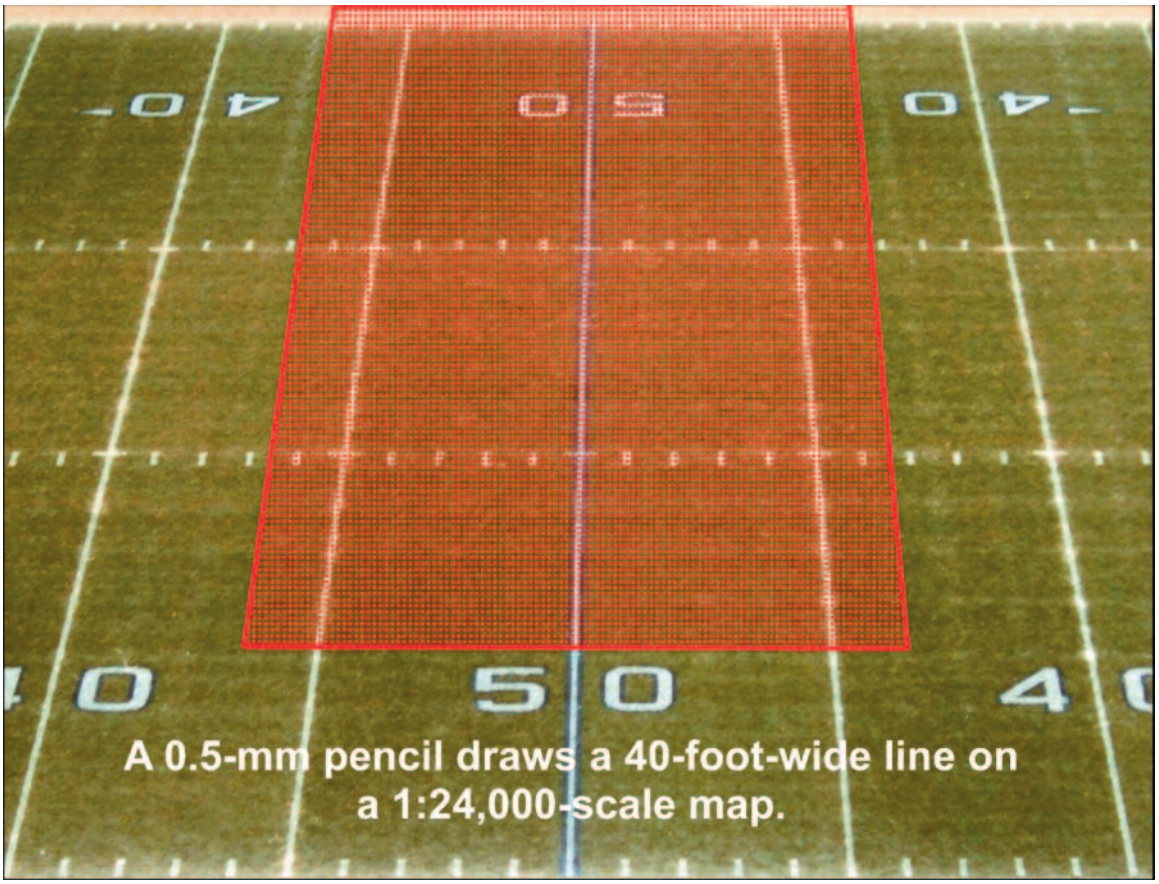

Figure 2. Football field at Beaver Stadium, The Pennsylvania State University. The field is marked off in yards. Note the width of a line (in red) drawn by a 0.5-mm pencil.

Therefore, a 1:24,000-scale map is a larger scale map than a 1:100,000-scale map, which is larger than the 1:250,000-scale map. Conversely, a 1:250,000-scale map is a smaller scale map than a 1:24,000-scale map.

Most large natural features, such as mountains, lakes, and rivers, are easily represented on a map at the map scale. Man-made features such as buildings or roads, however, sometimes cannot be portrayed at scale and still be seen on the map. Let's use roads as an example. According to PennDOT (Stephen Grimme, Mark Leitzel, and Martin Popola, personal communication, 2015), an average two-lane state road is about 20 feet wide from white line to white line. For Interstate roads, each travel lane is 12 feet wide. That would make one side of an Interstate road about 24 feet wide, with an inside shoulder of 4 feet and an outside shoulder of 8 to 10 feet. The Pennsylvania Tourism and Transportation Map mentioned before has a scale of about 1:500,000. Measuring on the map and then converting using the map's scale reveals that Interstate roads as shown on the map are about 1,670 feet wide, major highways are about 1,040 feet wide, and secondary roads are about 500 feet wide (Figure 4). That is acceptable because this map is drawn for navigation, so illustrating the networking and interconnections of the roads takes precedence. To display roads at their true width would make them impossible to see and defeat the purpose of the map.

The USGS has established map element display standards for their maps (Federal Geographic Data Committee, 2006; U.S. Geological Survey, 2003). Accordingly, line widths representing roads on USGS maps are 0.5 mm per lane, regardless of road type. Interstate medians may vary (Federal Geographic

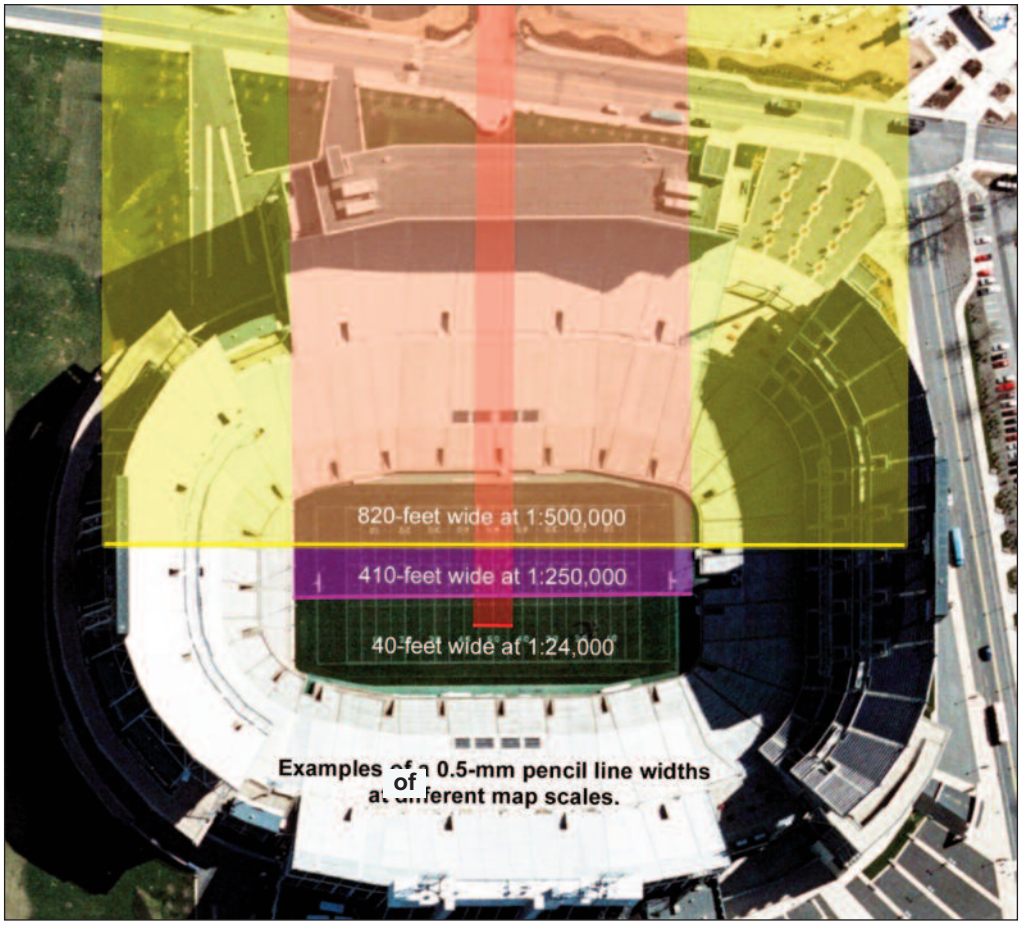

Figure 3. Example of the width of a 0.5-mm pencil line drawn on an aerial view of Beaver Stadium at Penn State at three different scales (red line at 1:24,000, pink-purple line at 1:250,000, and yellow line at 1:500,000). (Orthoimagery [2006] from PAMAP Program.)

Data Committee, 2006). Therefore, on a 1:24,000-scale map, road lanes are shown as 40 feet wide and get excessively wider as scale decreases.

Why is this important? Because this is how we map. We use scale and dimension all the time, often not realizing the graphic accuracy limitations of what we are illustrating.

Accuracy, Scale, and Precision—Uncomfortable Brothers

Accuracy, scale, and precision are all related to each other, but in different ways. Accuracy and precision are commonly used interchangeably even though they have completely different meanings. Precision refers to the exactness of the data or data with the least variation (Foote and Heubner, 1995). Precision is about repeatability of the data. Accuracy, on the other hand, is a measurement of how truly the data reflect what they are representing (Foote and Heubner, 1995). A paper map is produced at a defined scale so the data on the map are accurately represented at that scale. If more accurate data are used, they cannot be represented more accurately than the map's given or reference scale allows.

The USGS standard for horizontal accuracy for maps is that 90 percent of the features must be within 1/50 of an inch of their actual location, for scales of 1:20,000 or smaller (Foote and Heubner, 1995; U.S. Geological Survey, 1999). Thus, at 1:24,000 scale (Figure 5), features must have a probable location of within 40 feet of their actual location (Foote and Heubner, 1995).

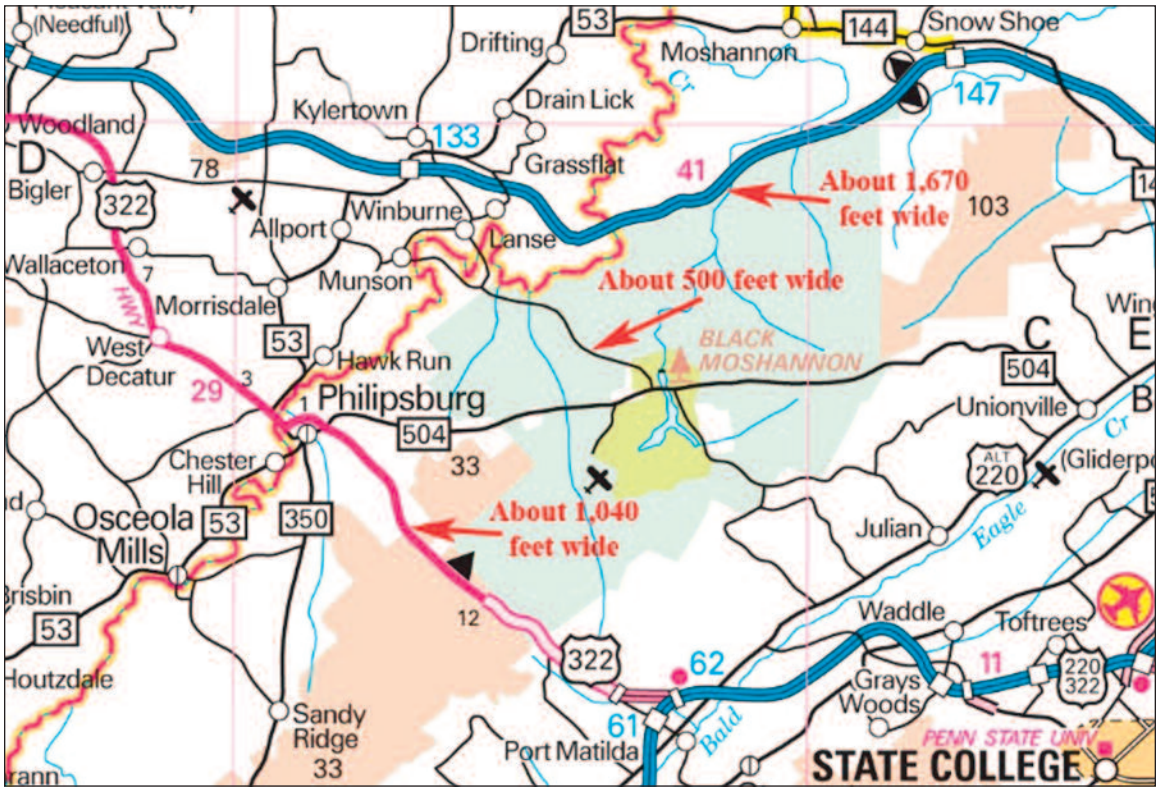

Figure 4. A portion of the Pennsylvania Tourism and Transportation Map (Pennsylvania Department of Transportation, 2016). Road symbolization widths as they would appear in feet on the ground are indicated on the map. Enlarged from 1:500,000 scale for clarity. (Base map reproduced courtesy of the Commonwealth of Pennsylvania, Department of Transportation.)

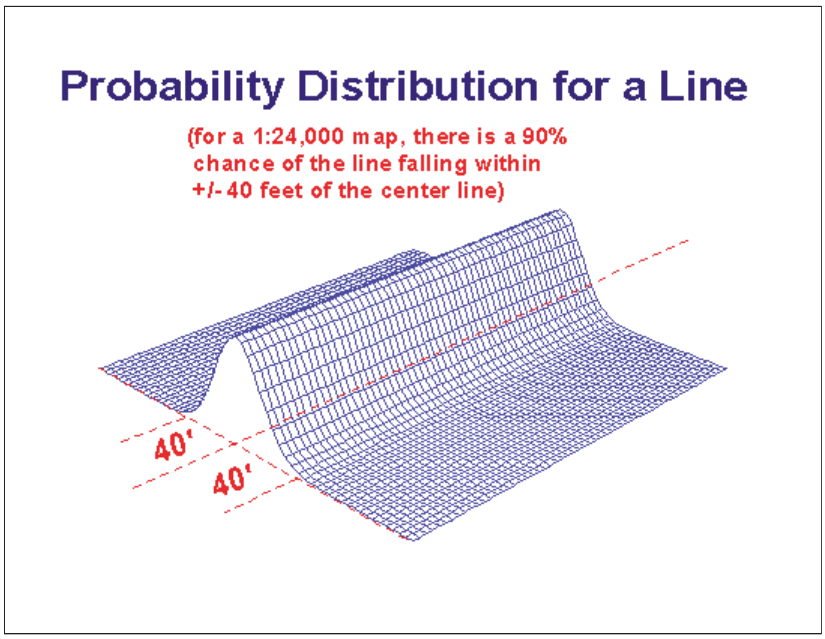

Figure 5. Line-placement probability on a 1:24,000-scale map (Foote and Heubner, 1995). Used with permission.

As an illustration of the difference between accuracy and precision, the left side of Figure 6 shows that it is possible to have very precise, highly inaccurate data. Although the holes form a tight cluster (are very precise), they are not at all accurate, lying outside of the zone of confidence for predicting the center of the target. The holes in the target on the right of Figure 6 are much more widely scattered (less precise) but more accurate, offering a more certain indication of the location of the target's center. In Figure 7, the tight cluster of holes on the left image is both precise and accurate, as the shooter is "certain" of the target center. Then, on the right image, there is always the "Dirty Harry" model, where

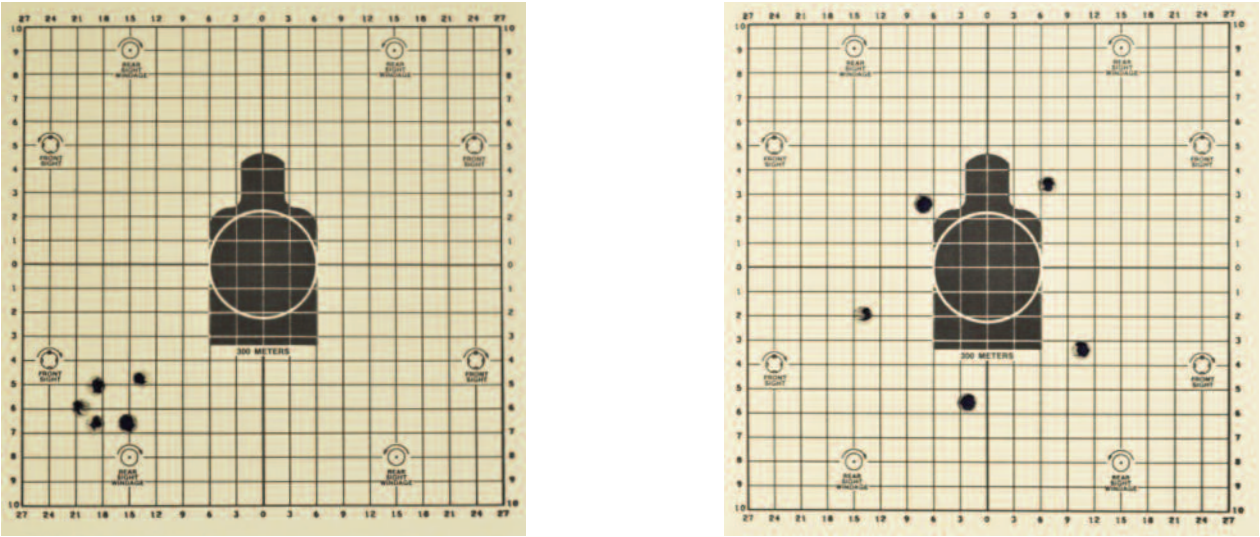

Figure 6. Results of target practice, illustrating the difference between accuracy and precision as discussed in the text. On the left image, although the data points are precisely grouped, we can only infer that the object target is there somewhere. The shooter could not find it. The right image approximates where the center object is located, but it was not hit directly.

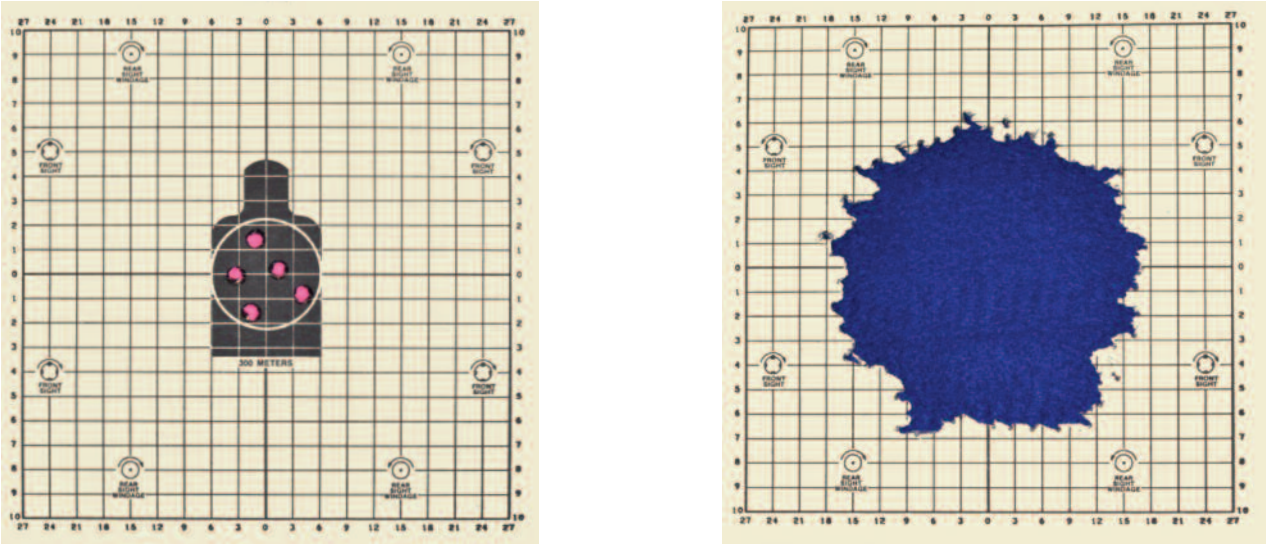

Figure 7. Additional results of target practice. The data points on the left target are both accurate and precise. The object center is located and observed; therefore the data points are certain. The right target speaks for itself.

precision and accuracy aren't really a factor. There is strong scientific evidence the object center was there at one time, but some sort of cataclysmic event removed it.

The delicate balance between scale, precision, and accuracy can be quite nebulous. How accurate are your data? How precise? What scale will your data accurately support? You may know the exact location of a geologic contact on the ground, but can you illustrate that accuracy, or lack thereof, on a map? Is your contact certain, approximate, or inferred (Federal Geographic Data Committee, 2006)? Figure 8 is a photograph of an observed sharp contact between the Ordovician Juniata (Oj) and Silurian Tuscarora (St) Formations. In Figure 9, although the observed Oj-St contact is certain, accurately locating this contact on a map is a function of how accurately the topographic features are depicted and the geologist's ability to interpolate where to draw the line (Federal Geographic Data Committee, 2006). Plus, at 1:24,000 scale, a 0.5-mm pencil contact line is still 40 feet wide. Decreasing the line width in an attempt to increase precision will not increase its accuracy beyond the 40-foot accuracy of the base 1:24,000-scale map.

Map scale has the unique ability to change data display accuracy. Data that meet the accuracy standards of a large-scale map retain that accuracy level. They can be drawn on smaller scale maps, but they cannot be displayed more accurately than the scale of the given map (Figure 9). Data that would be considered inaccurate on a large-scale map may be able to meet accuracy standards of a smaller scale map. As map scale decreases (zooming out), map accuracy standards also change proportionally, a key principle of generalization (Joao, 1998).

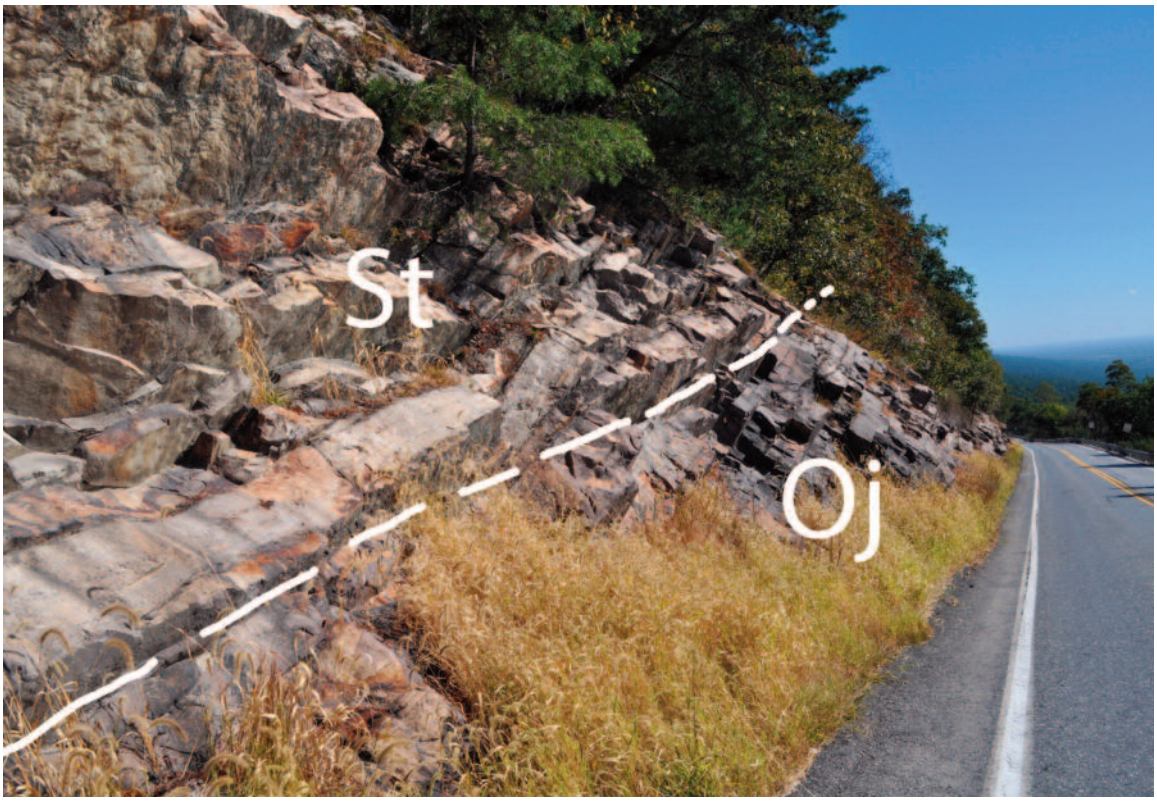

Figure 8. A sharp and certain contact between the Ordovician Juniata (Oj) and Silurian Tuscarora (St) Formations along Pa. Route 74 in Cumberland County, Pa. Shown as a dashed line so that the sharp contact can be seen.

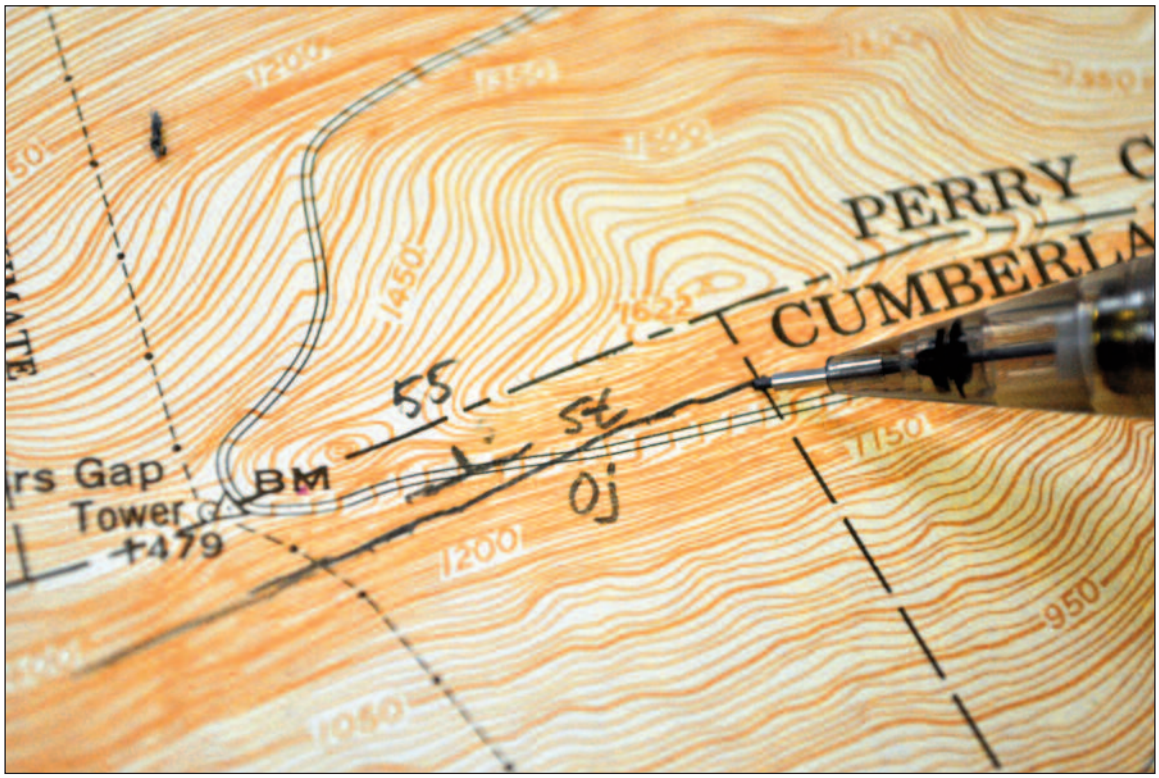

Figure 9. Locating and drawing the certain Oj-St contact on a 1:24,000-scale topographic map is a test of the geologist's interpolation skills.

Cartographic Displays, Maps, and Fitting It All Together

There are defined standards for how different map elements and objects are displayed on USGS maps (Federal Geographic Data Committee, 2006; U.S. Geological Survey, 2003). Man-made objects sometimes may not look like their representative symbols. A USGS standard house symbol is a 0.5-mm by 0.5-mm solid block (U.S. Geological Survey, 2003). This calculates out to a 40-feet by 40-feet block on the ground when shown on a 7.5-minute 1:24,000-scale map. Buildings are not illustrated at their actual dimensions until they are at least 100 feet in length (U.S. Geological Survey, 2003). That is why all the "house blocks" appear the same. Similarly, secondary highways and light-duty roads are symbolized as 0.5 mm wide (Federal Geographic Data Committee, 2006), which at 1:24,000 scale is a width of 40 feet (Figure 10). On smaller scale maps, buildings are usually not included. However, this is becoming a moot point, as the new all-digital topographic maps from the USGS National Map (http://nationalmap.gov/ustopo/index.html) no longer show structures as map elements. Instead, an imagery layer is included that shows actual buildings.

Changing map scales of a represented area can really cause complications for the cartographer, with many consequences and challenges. A printed map is a snapshot in time that displays data at a certain scale, accuracy, and projection. Many features are shown on maps, each as accurately represented as space allows. This can be quite challenging in tight areas such as narrow valleys. As map scale decreases, there is less space for feature display. Either cartographers make map elements extraordinarily small, making them difficult to see, or they generalize the map elements (Joao, 1998). In generalizing map elements, lines, for example, are smoothed. Multiple-line elements such as railroad

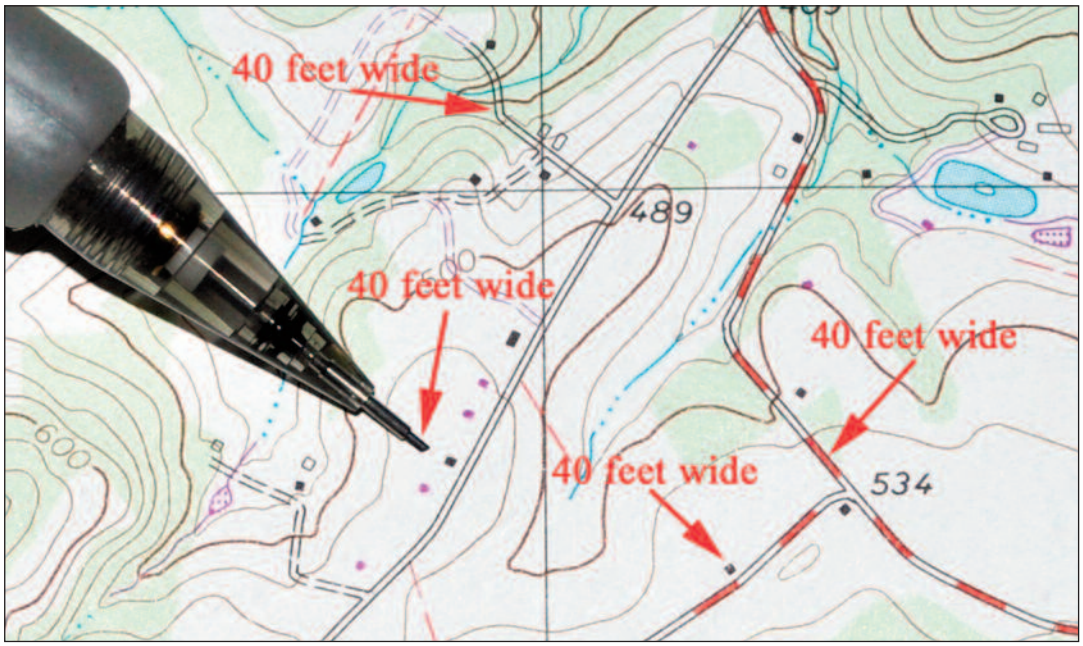

Figure 10. Examples of representative sizes of objects on a 1:24,000-scale map.

lines and multiple-lane roads are grouped into single lines, as are some double-line streams. Other closely spaced elements can be grouped together as one element. Even after generalization, map elements may not fit in the space available and still honor the accuracy of the map. Cartographic license allows deviation from normal rules in order to achieve a particular effect, such as making everything fit (Joao, 1998). Moving tight-fitting map elements is an accepted practice even though their location may not be exactly where they are on the ground.

Let us consider representing the Lewistown Narrows in Mifflin and Juniata Counties, Pa., on maps. This is a great example of generalization and cartographic license when dealing with multiple map elements in increasingly smaller spaces as map scale decreases. Figure 11 is a photograph of the Lewistown Narrows looking southwest into the valley. There are a major highway, a two-lane secondary highway, three rail lines, and the Juniata River. (In full disclosure, the various mapping examples shown predate the modern, four-lane U.S. Route 22/322 pictured below. At the time these examples were created, U.S. Route 22/322 was a slightly narrower three-lane highway.) Figures 12 through 14 are parts of topographic maps showing the Lewistown Narrows at decreasing map scales. Each is slightly enlarged so that the viewer can see the progression of generalization and cartographic license as map scale decreases. At 1:24,000 scale (Figure 12), there is enough space to illustrate many of the features in the valley as map elements. At 1:100,000 scale (Figure 13), the rail lines are represented by a single line. The roads are smoother and proportionally wider. Most of the detail on the valley floor has been removed. At 1:250,000 scale (Figure 14), the roads are still wider and smoother, and they have been moved upslope to fit. The Juniata River is reduced to mostly a single line and is crowded by the single railroad line. By necessity, map elements drawn on a 1:250,000-scale map are much more generalized than those drawn on a 1:24,000-scale map, but they are still considered accurately placed at that map scale.

Figure 11. Photograph of the Lewistown Narrows, Mifflin and Juniata Counties, Pa., looking southwest.

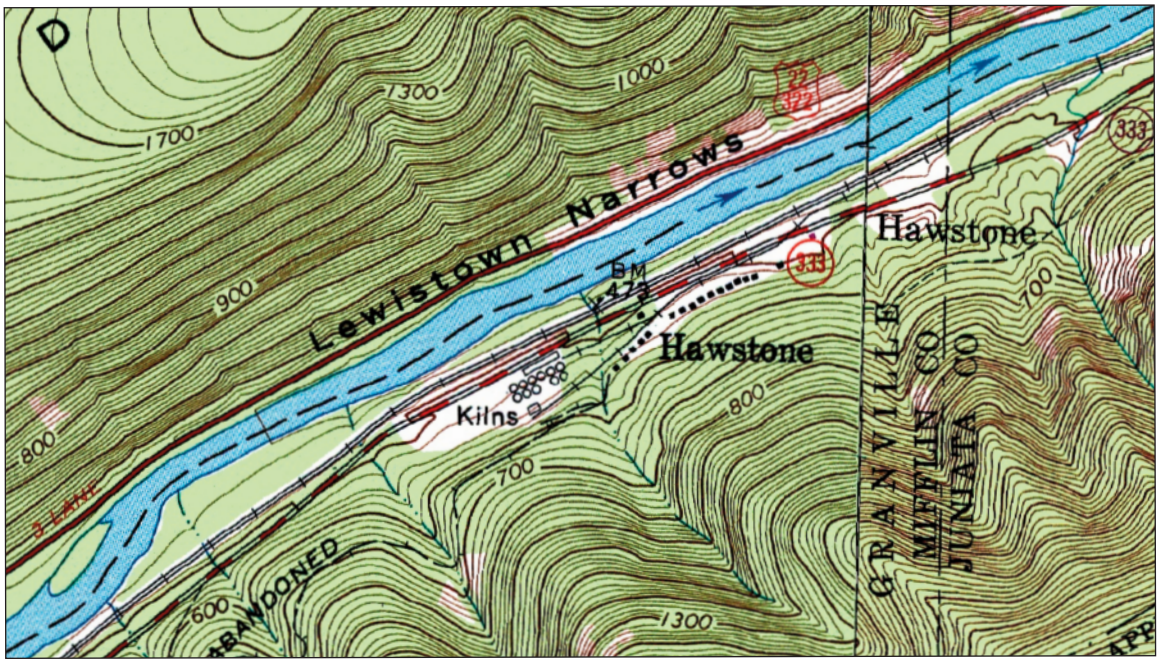

Figure 12. The Lewistown Narrows as represented at 1:24,000 scale on portions of the Lewistown and Mifflintown 7.5-minute quadrangle maps. Note the detail of objects on the valley floor such as the kilns, which are no longer there.

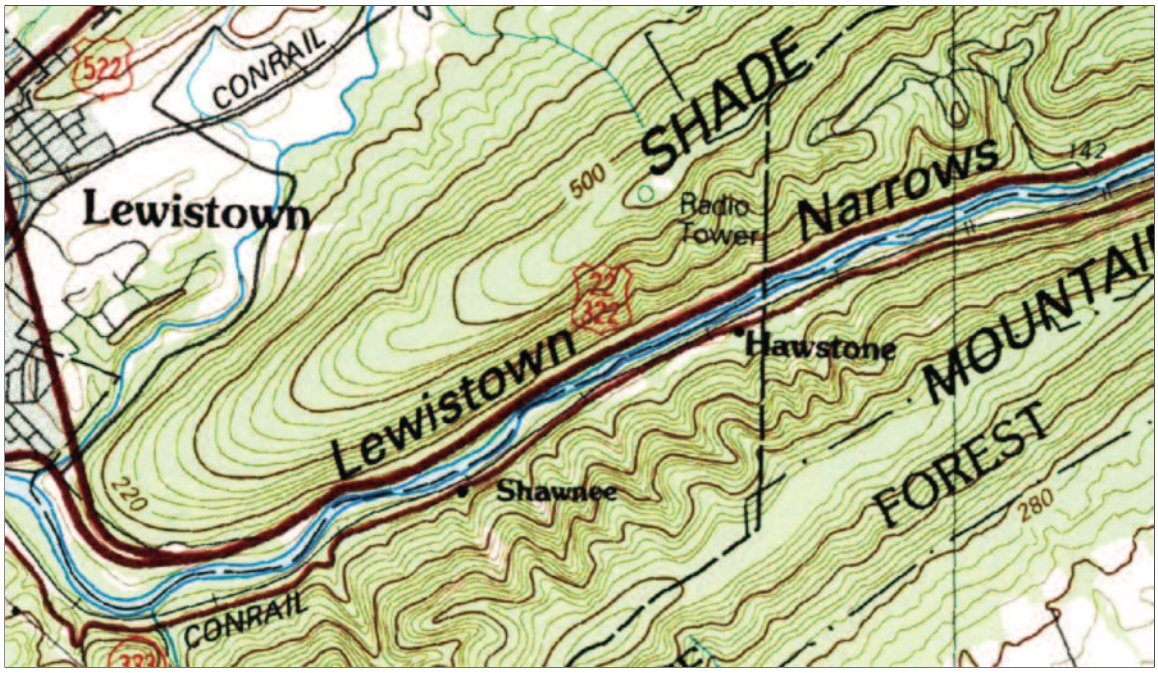

Figure 13. The Lewistown Narrows as represented on the State College 1:100,000-scale quadrangle map. On this smaller scale map, some feature generalization can be seen, and buildings and other smaller elements have been removed.

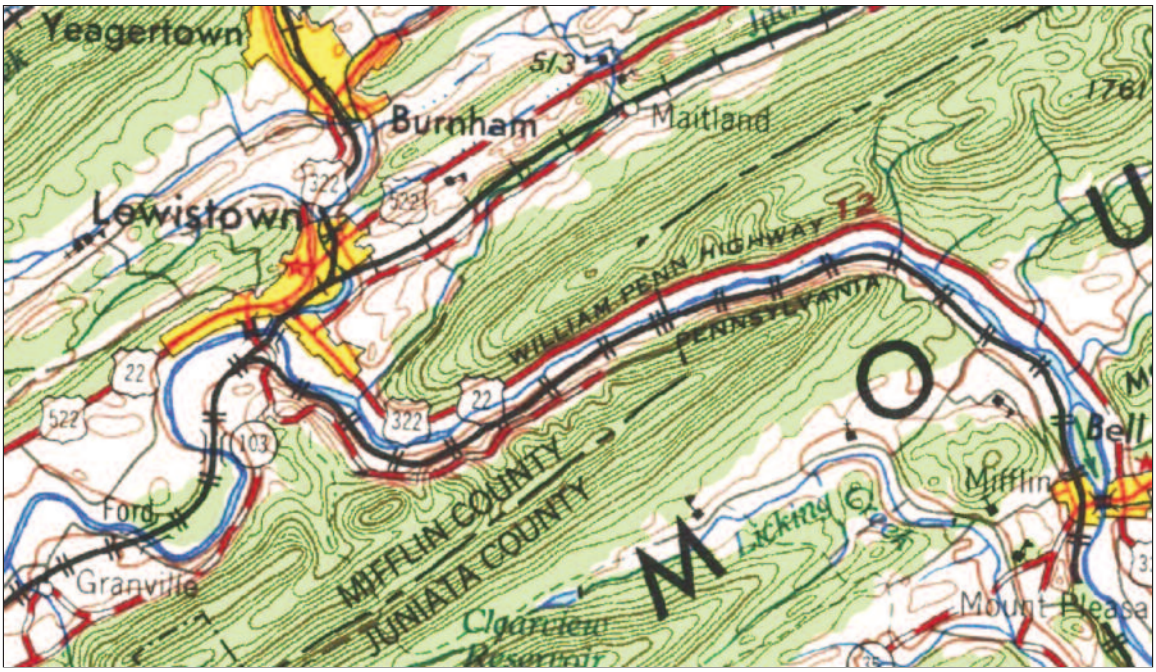

Figure 14. The Lewistown Narrows as represented on the Harrisburg 1:250,000-scale quadrangle map. Map element generalization is very apparent. Many details have been removed, and cartographic license was used to better fit closely spaced features in the narrow valley.

As illustrated by the map images in Figures 12, 13, and 14, scale dictates the relative amount of detail that can be used to effectively portray features the maps represent. Although cartographic license is used, these maps meet the accuracy standards for their respective scales.

GIS, GPS, and the Complications of New Mapping Technology

As you might imagine, scientific interpretations can be complicated when combining maps and data that were generated at different scales. Even though each piece of information meets the accuracy standards under which it was created, sometimes they do not appear to align with each other. Enlarging a 1:250,000-scale geologic paper map on a copier to match a 1:24,000-scale map only makes the contact lines wider. It becomes a test of the geologist's ability to interpolate where lines could be realistically located, knowing that they could be anywhere within the enlarged line. There is also the overriding question of data accuracy when small-scale map data are placed on larger scale maps. We will discuss this complication later.

GPS devices, another tool in the toolbox, have improved location coordinate accuracy and precision dramatically; however, there are a couple of things to consider when using GPS coordinates at various map scales. The number of significant digits at the end of the coordinate pairs decreases as map scale decreases. There may be many numbers to the right of the coordinate's decimal points, implying very high precision, but their validity depends on the scale of the base map. As pointed out earlier, you cannot display your data point more accurately than your base map allows. Another caveat is that GPS was not around when many maps were constructed. Features may be accurately located at the base-map scale, but not for GPS. So the question becomes: if you are standing on the north side of a road and your GPS coordinates place your point on the south side of the road on your base map, do you choose the accurate GPS position or the visually accurate map graphic position?

GIS is another revolutionary development in everything spatial. It is a software and database system of tools that allows the integration and analysis of many sources of spatially based information (Foote and Lynch, 1995). GIS allows the user to utilize data regardless of differing scales and projections. GIS mathematically interprets data so that they can all be layered and viewed at the same time, in the same projection, and at the same scale. Data accuracy remains static, however, even though the screen display (scale) can be zoomed in and out with great ease.

Herein lies a problem. False accuracy and precision are inherent dangers in GIS, as it implies accuracy and precision far beyond the data's ability to support them (Foote and Heubner, 1995). As you may recall from high school geometry, a line, by definition, is one-dimensional. It has length, but no width. By default, a GIS line honors this definition. A GIS line on the screen is a few pixels wide so that you can see it, regardless of zoom level (scale). The line width remains at virtual zero no matter what. On a paper map, line widths are based on symbology standards, base-map scale, and linear units defined by the map's projection (Federal Geographic Data Committee, 2006). In GIS, line display widths are defined by the same parameters. Once a reference scale is set in GIS, line widths and other symbols will change size relative to scale changes (zooming in and out). The earlier football field illustration shows how line widths change as the map reference scale changes (Figure 3).

The Geologic Map of Pennsylvania (paper Map 1) (Berg and others, 1980) was published at a scale of 1:250,000, which is its intended accuracy. When this same map was compiled into digital GIS datasets (digital Map 1) (Miles and Whitfield, 2001), it was digitized mostly from the original compilation sources. In some places, the source compilation data were more accurate; however, the dataset accuracy

is still 1:250,000 scale. Using GIS, these 1:250,000-scale digital geologic data can be easily overlain on a 1:24,000-scale base map. Although the accuracy is now implied to be 1:24,000 scale, it most certainly is not. The following examples demonstrate why this is such an important concept.

The geology source for paper Map 1 for the Womelsdorf quadrangle area was originally from Atlas 177c of the Pennsylvania Geological Survey, published at 1:24,000 scale (Geyer and others, 1963). Figure 15 is a portion of Plate 1 of Atlas 177c that shows the level of geologic detail at 1:24,000 scale. This level of detail was not possible when the data were compiled for paper Map 1 or digital Map 1 (Berg and others, 1980; Miles and Whitfield, 2001). It was necessary to use generalization and cartographic license to accurately represent this geology at 1:250,000 scale. Figure 16 illustrates the scale disparity between the Womelsdorf 1:24,000-scale quadrangle map and the 1:250,000-scale digital Map 1 geology of the same quadrangle.

Using GIS, the 1:250,000-scale digital Map 1 geology can be digitally "stretched" to fit the 1:24,000-scale map. Figure 17 is the 1:250,000-scale geology of the same area of the Womelsdorf quadrangle as Figure 15. Using GIS, this area was zoomed in to 1:24,000 scale; however, the line widths and polygon symbolizations remain at the original 1:250,000 reference scale. Much like the enlarging copier, the line widths are exceedingly wide and the polygons are generalized and bulkier. This illustration shows how the true accuracy of 1:250,000-scale geologic data appears when it is used at a larger scale far beyond the data's ability to support it. In Figure 18, the same 1:250,000-scale geology's symbolization reference scale is reset to 1:24,000 scale, the same as the base quadrangle map. Comparing Figure 15 and Figure 18, it is easy to see the generalization and cartographic license used to make this complex geology fit in its allotted 1:250,000-scale compilation space. It is also easy to see

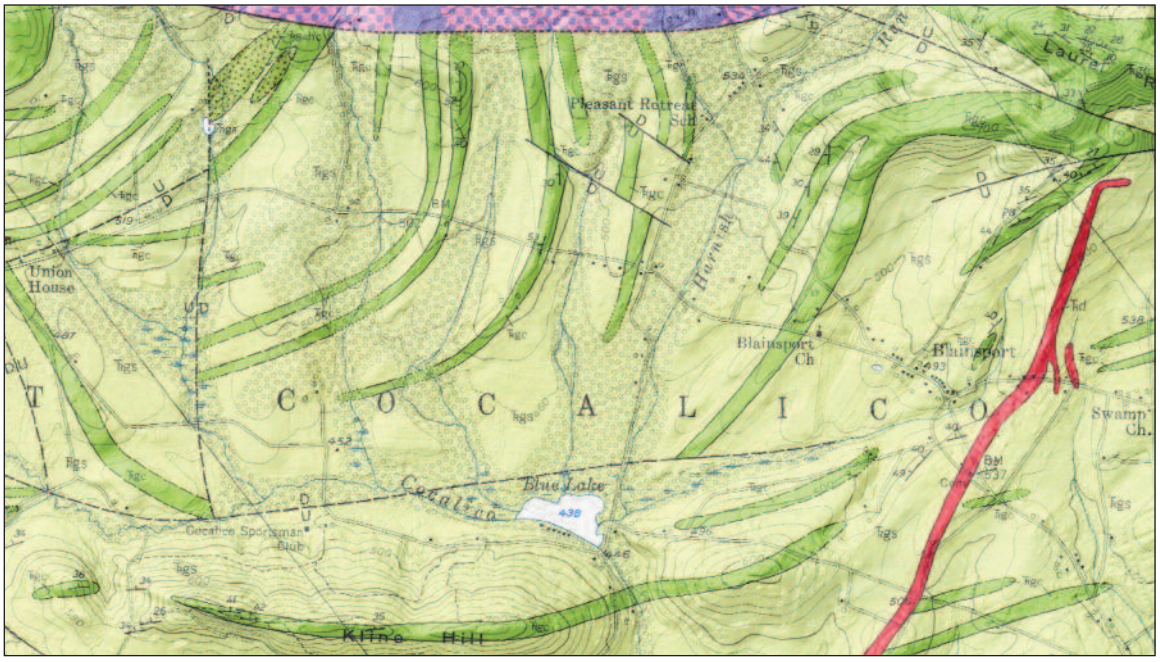

Figure 15. A portion of Atlas 177c, Plate 1 (Geyer and others, 1963), showing detailed Triassic geology of the Womelsdorf 1:24,000-scale quadrangle map. This map was used as source data for both the paper and digital Map 1 (Berg and others, 1980; Miles and Whitfield, 2001).

Figure 16. Scale disparity between the 1:250,000-scale geology from Map 1 for the Womelsdorf quadrangle (small rectangle in the center) and a 1:24,000-scale Womelsdorf topographic map.

Figure 17. Using GIS, the same portion as Figure 15 of the Womelsdorf 1:24,000-scale quadrangle map is overlain with 1:250,000-scale digital Map 1 geology. The geologic lines and polygons are symbolized at their true accuracy of 1:250,000-scale. Note the excessive line widths. Exactly where are the contacts?

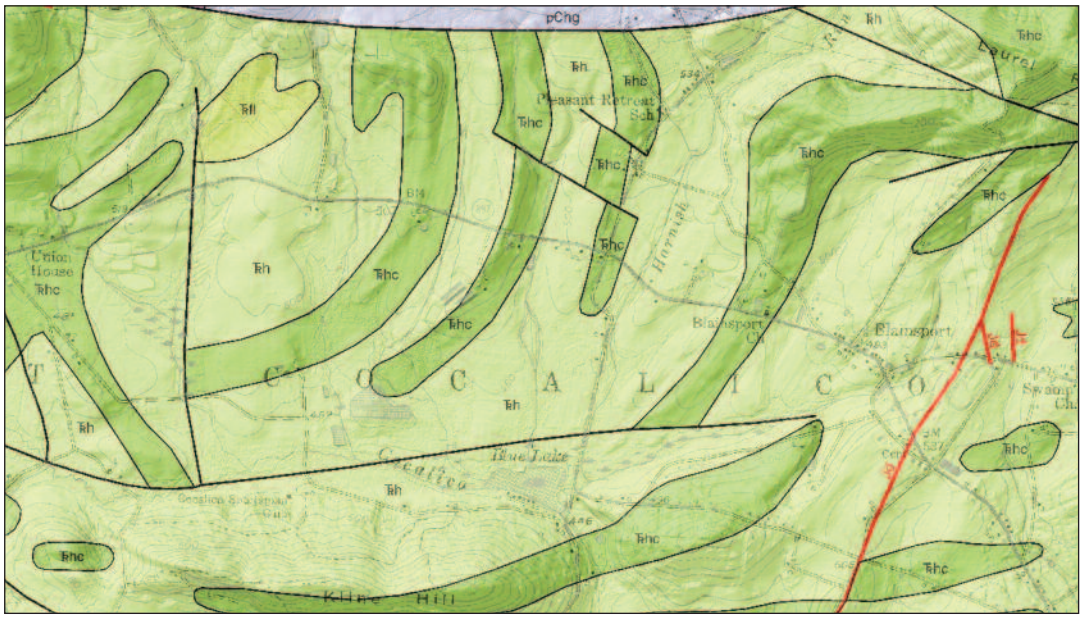

Figure 18. This is the same area as that shown in Figure 17 with the 1:250,000-scale geology reset to what would be used for 1:24,000-scale geology. Here we can see how much Atlas 177c geology was greatly generalized and simplified, and how much cartographic license was used. It also demonstrates how inappropriately overlain data can be made to look very authentic.

how inaccurate the 1:250,000-scale geology becomes when it is inappropriately placed on a larger scale base map as opposed to the actual 1:24,000-scale geology in Figure 15. The geology in Figure 18 appears to be accurate because it is symbolized at 1:24,000 scale. The thinner lines appear normal to the user, causing him/her to disregard the fact the data are generalized and highly inaccurate. This disregard adds false authentication, rather than reflecting the data's true accuracy.

Concluding Thoughts

Scale is not just a simple bar or ratio fraction on a map. Scale is a matter of both accuracy and abstract thinking. Accuracy is a complex mixture of many factors that change as scales change. What are the accuracy differences in your data sources? What is your base reference scale? How will generalization affect your data? Will it still maintain accuracy? How can you accurately illustrate what you want to show? Technological advancements such as GIS are a boon to our understanding but add to the complications of mixed accuracy sources. Scale abuse, often unintentional, is all too common. Scale and accuracy are no longer interchangeable terms. Let us again consider the definition of scale:

> **"2.a. The proportion used in determining the relationship of a representation to that which it represents."**

There are many questions to think about the next time you look at a map. What compromises did the author use to synthesize the data? How did these compromises influence the interpretation? At this scale, what compromises were made to create this map? Is this map a true representation of what it is intended to represent?

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BUREAU NEWS

Improvements in the Pennsylvania Groundwater Information System (PaGWIS)

The Pennsylvania Groundwater Information System, known as PaGWIS, has been around in one form or another since 1998. However, the history of water-well data collection goes back further than that, as summarized below:

- The Pennsylvania Geological Survey started collecting well records from water-well drillers on paper forms in 1965, and for years, the only way to see the data was to visit the bureau's Harrisburg office.
- In 1969, we began entering the data (initially on punch cards) from the paper forms into a digital database, which was the forerunner of PaGWIS. Users eventually could request county or township reports compiled by bureau staff from the database.
- In 1998, we created PaGWIS by combining our driller-submitted water-well records with data from several outside sources. We made the entire database available in Microsoft Access format on CD-ROM.
- We converted PaGWIS to an online database that was available to the public on our web page in 2004. It included a search tool for online data extraction. However, the online extraction produced only a basic report that contained a small portion of the data contained in PaGWIS.
- Now, in 2016, we have improved the search tools, and the user can now extract online virtually all of the data available in PaGWIS. Staff geologists Gary Fleeger and Stuart Reese developed most of the conceptual changes and database mapping and performed testing on the new PaGWIS site.

As a repository of hundreds of thousands of water-well records, PaGWIS continues to grow and function as an important source of groundwater data. The database has grown to more than a half million water-well and spring records. New search tools, data packages, and report formats are the key improvements of PaGWIS. Getting data out of PaGWIS has never been easier, and the system now includes several type of reports and downloads for different users and their many purposes.

Well Searches

There are 2 search screens for doing well searches in PaGWIS. Both will likely provide you with a list of wells of possible interest. Because few wells in PaGWIS have been located in the field, most do not have precise locations, and you will want to select the wells from the resulting list.

- The Multiple Criteria Search (Figure 1) allows you to enter various criteria to produce a list of wells or springs. The more criteria you can enter, the shorter your list of wells will be.
- The Map Search screen (Figure 2) provides you with a map or aerial photograph, where you can digitally draw a circle or rectangle to select the wells or springs within that circle or rectangle. An important improvement in PaGWIS is the ability in the Map Search to include records that do not have coordinates but could be in the search area based on what municipalities are intersected. A check box can be selected to include such records.

The method that you choose depends on the information that you have available.

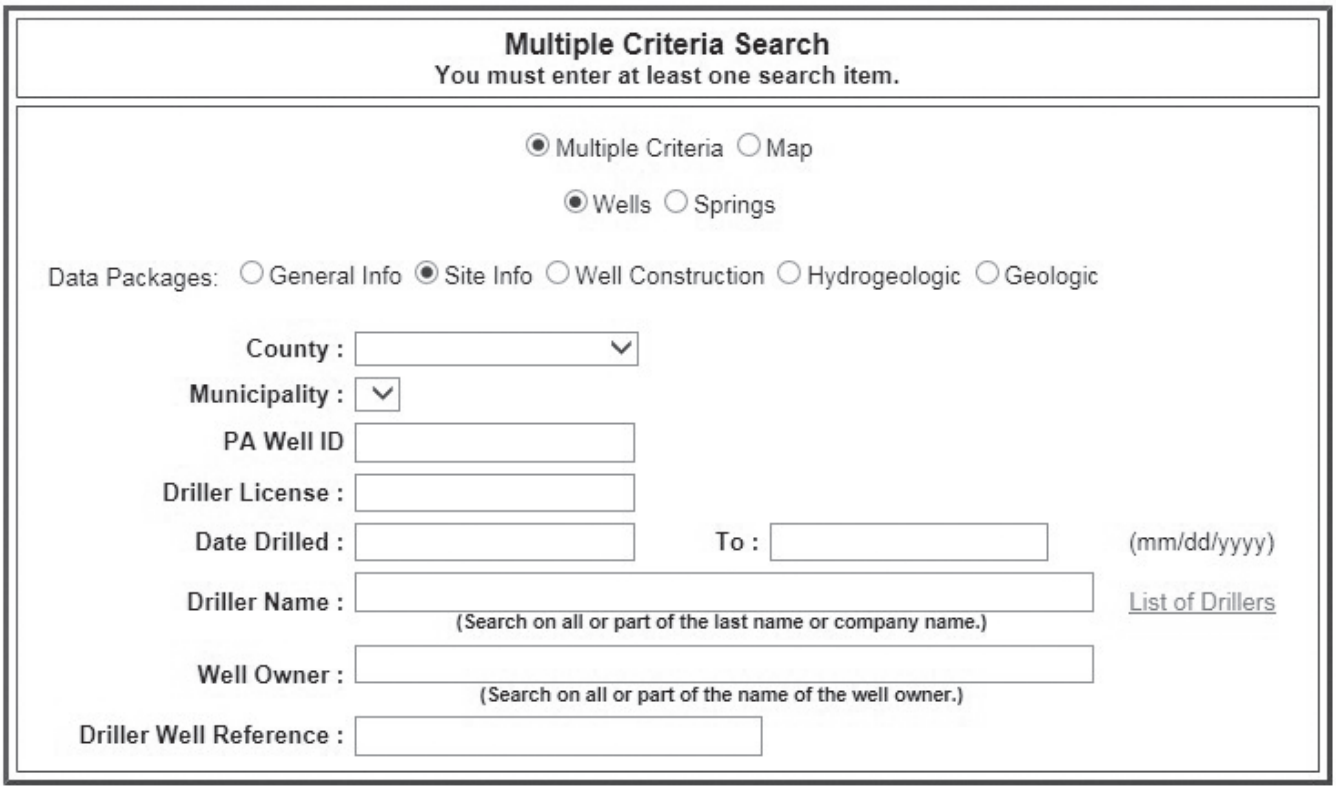


Figure 1. Multiple Criteria Search screen.

Available Data

Once you find the well(s) or spring(s) of interest, what information can you see, and in what format?

Some homeowners use PaGWIS to find a record of their water well that was drilled before they moved into their home. For those who own a private water well, finding the original well report can be a daunting task.

Once you have found your well, you can look at the complete well report. The individual well report (Figure 3) was completely reformatted to create categories of data such as location information, well construction data, and groundwater and geological information. Most reports can now be printed on one sheet of paper. There are similar reports for springs.

If your well record was originally submitted to us by the driller on a paper form, that form, if it is available, can also be viewed (Figure 4). There may be some additional notes or information that are not included in the database report. There is no corresponding paper form for any of the spring data.

Other users might want to obtain information on the geology, groundwater, or well construction in an area, rather than see the record for a single well. For these users, different packages (Figures 1 and 2) of data can be downloaded as a spreadsheet. Each package contains a different type of information—Well Construction, Hydrogeologic, or Geologic. There is also a Site Info package, which provides location information and other information about the site, and a General Info package, which provides some information from all of the other data packages. One field that is common to all data packages is

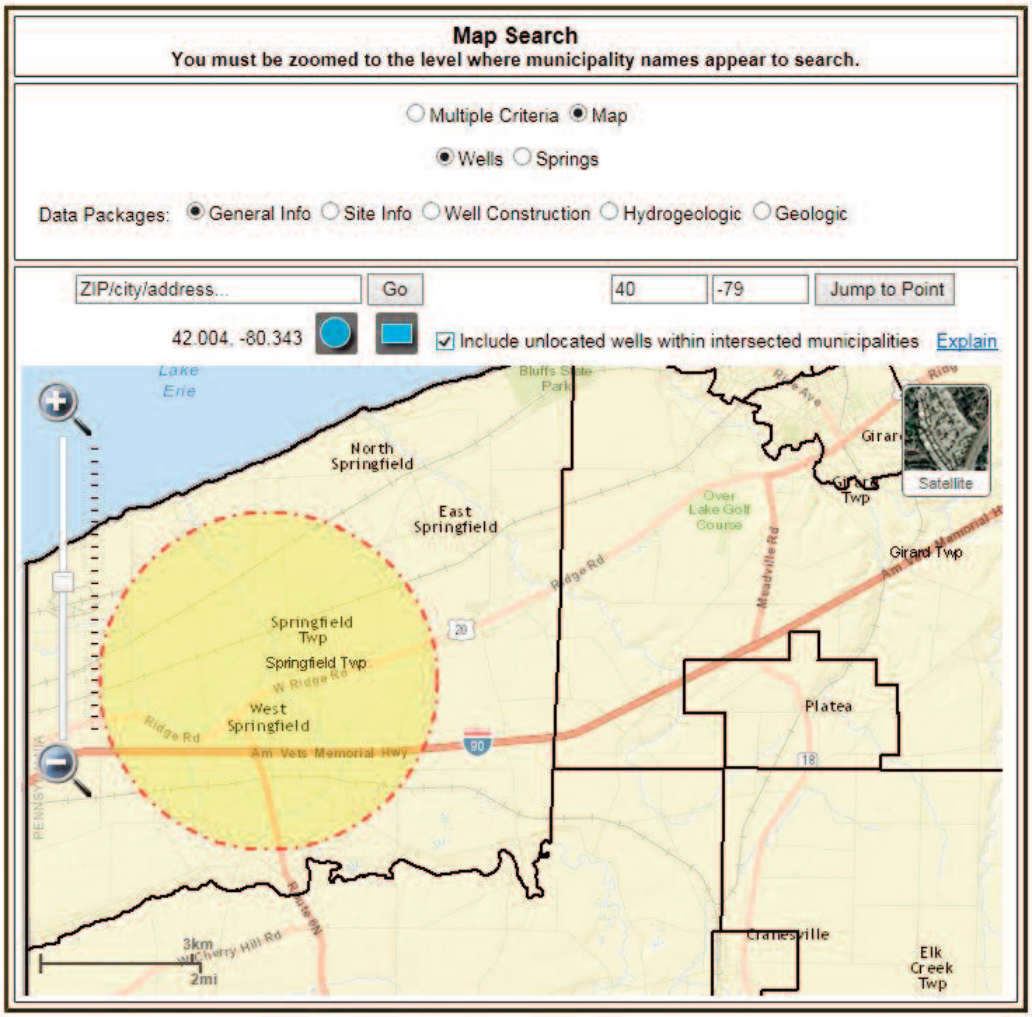


Figure 2. Map Search screen. Dashed circle outline indicates search area. Black lines are municipality boundaries. Note the different data packages. A street address can be entered as a starting point, but many addresses have changed from Rural Delivery numbers (when the well was drilled) to street numbers and are not in PaGWIS.

the PA Well ID. Using this unique identification number, you can link data from different data packages for the same well.

The PaGWIS web page allows a user to view or download data about individual water wells and springs, or, using either search method, to download various data packages. However, PaGWIS does not contain water-quality information, nor, for homeland security reasons, any information on public water-supply wells or springs.

The improvements allow the user to more readily access valuable water-resources data. For example, a recent phone caller to the bureau requested groundwater information in Erie County. The caller, a licensed water-well driller, was trying to understand the potential for a new campground water source in Springfield Township (Figure 2). He had not drilled in this area before.

Water Well Information Report Page 1 of 1

DEPARTMENT OF CONSERVATION & NATURAL RESOURCES
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
WATER WELL PROGRAM
3240 Schoolhouse Rd
Middletown, PA 17057
717-702-2017

WATER WELL INFORMATION REPORT

PA Well ID: **641043** Local Well ID: Local Permit #:

LOCATION INFORMATION

Owner:		Original Paper Record Image Available:	**Yes**
Address of Well:	**22492 St Hwy 285, Cochranton 16314**		
County:	**CRAWFORD**		
Municipality:	**FAIRFIELD TWP.**		
Latitude:	**41.52892**	Coordinate Method:	**Commercial Street Atlas Program**
Longitude:	**-80.08675**	Data Reliability:	**LOCATION MAY NOT BE ACCURATE (WWI paper)**
Description of Well Location and Other Notes:	**.4 mi from Peterson Rd on 285.**		

WELL CONSTRUCTION INFORMATION

Well Driller:	**BOOKAMER DRILLING COMPANY**	License:	**1786**	Driller Well ID:	
Type of Activity:	**New Well**	Date Drilled:	**10/1/2015**	Drilling Method:	**CABLE TOOL**
Well Depth (ft):	**64**	Well Finish:	**OPEN END**		

WELL SIZE

Top (ft)	Bottom (ft)	Diameter (in)
0	**64**	**6**

CASING

Top (ft)	Bottom (ft)	Diameter (in)	Casing Material	Seal Top	Seal Bottom	Seal Type
0	**65**	**6**	**STEEL**			**NONE**

GROUNDWATER AND GEOLOGICAL INFORMATION

Well Yield (GPM - gal per min):	**20**	Yield Measurement Method:	**UNKNOWN**
Water Level when not pumped: (ft below land surface)	**24**	Water Level after yield test: (ft below land surface)	**50**
Length of Yield Test (minutes):	**60**	Saltwater Zone (ft):	
Use of Well:	**WITHDRAWAL**	Use of Water:	**DOMESTIC**

MATERIALS WELL PENETRATES

Top (ft)	Bottom (ft)	Description
0	**18**	**Br. Cl and Gr**
18	**33**	**Bl. Clay**
33	**59**	**Bl. Cl. and Gr.**
59	**64**	**Gr. and Water**

LEVELS WHERE WATER ENTERS WELL

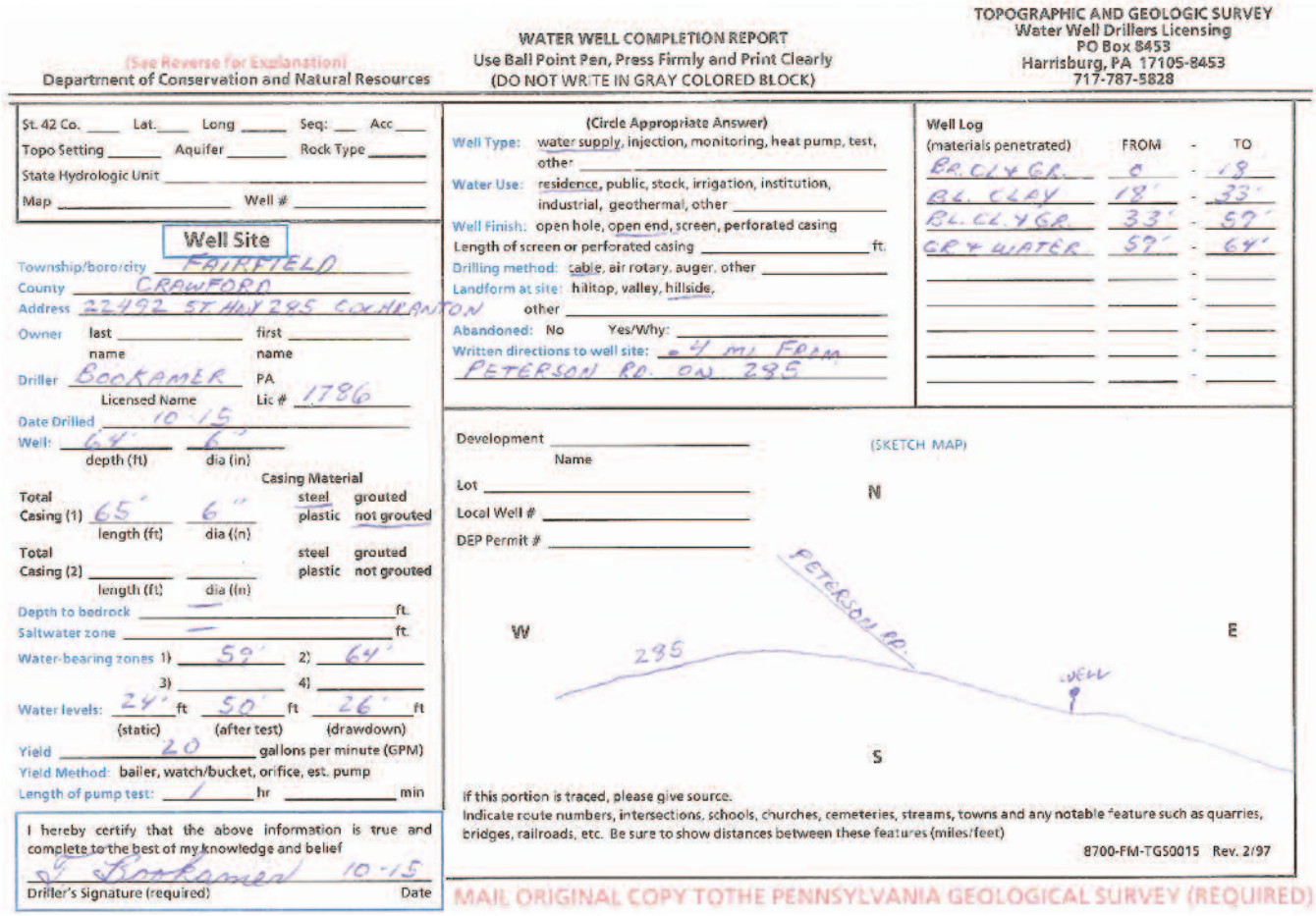
Top (ft)	Bottom (ft)	Yield (GPM)
59		
64		

Depth to Bedrock (ft): **64** Was Well Drilled Into Bedrock? **No**

Date Printed: **7/28/2016**

http://www.iframeappstest.dcnr.state.pa.us/topogeo/PaGWIS_Search/DisplayReportDetails.aspx?id=6410... 7/28/2016

Figure 3. Example of a reformatted individual well report.



(See Reverse for Explanation)
Department of Conservation and Natural Resources

WATER WELL COMPLETION REPORT
Use Ball Point Pen, Press Firmly and Print Clearly
(DO NOT WRITE IN GRAY COLORED BLOCK)

TOPOGRAPHIC AND GEOLOGIC SURVEY
Water Well Drillers Licensing
PO Box 8453
Harrisburg, PA 17105-8453
717-787-5828

St. 42 Co. ___ Lat. ___ Long ___ Seq: ___ Acc ___
Topo Setting ___ Aquifer ___ Rock Type ___
State Hydrologic Unit ___
Map ___ Well # ___

Well Site
Township/borough/city FAIRFIELD
County CRAWFORD
Address 22492 ST. HWY 285 COCHRANTON
Owner last name ___ first name ___
Driller BOOKAMER PA Lic # 1786
Licensed Name
Date Drilled 10-15
Well: 64' depth (ft) 6" dia (in)
Casing Material
Total Casing (1) 65' length (ft) 6" dia (in) steel plastic grouted not grouted
Total Casing (2) ___ length (ft) ___ dia (in) steel plastic grouted not grouted
Depth to bedrock ___ ft.
Saltwater zone — ft.
Water-bearing zones 1) 59' 2) 64' 3) ___ 4) ___
Water levels: 24' ft (static) 50' ft (after test) 26' ft (drawdown)
Yield 20 gallons per minute (GPM)
Yield Method: bailer, watch/bucket, orifice, est. pump
Length of pump test: 1 hr ___ min

I hereby certify that the above information is true and complete to the best of my knowledge and belief
D. Bookamer 10-15
Driller's Signature (required) Date

(Circle Appropriate Answer)
Well Type: water supply, injection, monitoring, heat pump, test, other ___
Water Use: residence, public, stock, irrigation, institution, industrial, geothermal, other ___
Well Finish: open hole, open end, screen, perforated casing
Length of screen or perforated casing ___ ft.
Drilling method: cable, air rotary, auger, other ___
Landform at site: hilltop, valley, hillside, other ___
Abandoned: No Yes/Why: ___
Written directions to well site: .4 MI FROM PETERSON RD. ON 285

Well Log
(materials penetrated) FROM - TO
BR. CLY & GR. 0 - 18
BL. CLAY 18' - 33'
BL. CLY & GR. 33' - 59'
GR & WATER 59' - 64'

Development ___ Name
Lot ___
Local Well # ___
DEP Permit # ___

(SKETCH MAP)
N
W
E
S
PETERSON RD.
285
WELL

If this portion is traced, please give source.
Indicate route numbers, intersections, schools, churches, cemeteries, streams, towns and any notable feature such as quarries, bridges, railroads, etc. Be sure to show distances between these features (miles/feet)

8700-FM-TGS0015 Rev. 2/97

MAIL ORIGINAL COPY TOTHE PENNSYLVANIA GEOLOGICAL SURVEY (REQUIRED)

Figure 4. Example of an original paper well record submitted by the driller. It contains some additional information not on the PaGWIS report, such as the landform at the site, if the well was abandoned, and a sketch map of the location.

A quick download of PaGWIS records for the township opened in a spreadsheet. The download contained more than 100 wells. Well yields ranged from 0 to 48 gallons per minute (gpm). A quick calculation of the median yield for all wells indicated only 4.5 gpm, which means half of the wells had yields less than 4.5 gpm. This is not very much water, especially for a campground! Another interesting piece of information was that the median well depth was 50 feet. Most of the wells installed in the township were less than 100 feet deep. The median static water level was 17.5 feet. A review of the water-bearing zones (WBZ) from the "Hydrogeological" data package showed that nearly all identified WBZs were less than 100 feet below the surface. All these data showed the driller a picture of what to expect.

In addition, the bureau also provides more free information through the web mapping application, PaGEODE. Using the address locator or zoom controls, the user can focus in on the area of interest. For this campground area, the bedrock beneath the site is the Girard Shale, which is "light to medium gray, very fine grained, and argillaceous, and has some siltstone." A publication search of PaGEODE for Water Resource reports retrieved the bureau's 1987 Water Resource Report 62, *Groundwater Resources of Erie County, Pennsylvania* (by D. B. Richards, H. J. McCoy, and J. T. Gallaher). This publication provides an overview of groundwater in the county, including details on the Girard Shale. Notably, the

authors of the report summarized the Girard Shale as the "poorest aquifer in Erie County," with a median yield of 2 gpm and "excessive dissolved solids and iron concentrations in some places." The bedrock of Erie County is almost entirely overlain by glacial deposits, and for some locations, the deposits are thick enough to be adequate aquifers (PaGWIS data indicate that the average depth to bedrock in this area is 54 feet). A check of the PaGWIS wells shows that indeed, some drillers target the glacial sediments and use large-diameter wells to maximize the groundwater yield. For the driller, this is also critical information. Accessing the PaGWIS data and water-resource report helps the user to outline possible strategies to acquire an adequate water source.

PaGWIS does have limitations, which we are gradually addressing: wells with imprecise or inaccurate locations, missing coordinates, other omitted information, inadequate descriptions of the subsurface, and completely absent records. But the wealth of information that it does contain is now easily available at the click of a button. PaGWIS also contains more than 1,600 spring records. Continual efforts have improved the system, though work remains to be done.

The PaGWIS website can be accessed at www.dcnr.state.pa.us/topogeo/groundwater/pagwis/.

Acknowledgments

The Department of Conservation and Natural Resources, Bureau of Information Technology, provided hundreds of hours of technological support. Earl Stoltzfus, Ryan Morgan, Mike Bialousz, Carrie Tropasso, and Steven Kantes oversaw and completed the coding portion of the work for the graphical user interface, data-package downloads, and website revisions, including the construction of the Map Search tools.

—Stuart O. Reese and Gary M. Fleeger

NEW RELEASES

Full Steam Ahead

Boaters and anglers can now access three more depth and fish habitat maps of lakes at their favorite state parks! Maps of Cowans Gap Lake at the park by the same name (Figure 1), Laurel Lake at Pine Grove Furnace State Park, and Lake Frances at Nescopeck State Park are now available. Maps include depth contours, fish habitat, and park amenities of interest to boaters and anglers.

Data have been collected at five additional lakes in four parks, including Promised Land Lake and nearby Lower Lake, Yellow Creek Lake, Nockamixon Lake, and Little Pine Lake. Data will be processed this fall and winter. By spring, 31 state park lake maps will be available. These maps are also useful to park and resource managers, who can derive average depth, reservoir volume, and flood-storage potential from the associated map data.

Park resource managers are making next year's priority list, and bureau staff members are on track to complete maps for lakes in 46 Pennsylvania state parks by 2019. The variety of lake sizes, depths, vegetation, wildlife, and park users continues to amaze and impress the data-collecting staff.

Maps can be accessed from each park's web page or from the bureau's website at www.dcnr.state.pa.us/topogeo/publications/pgspub/openfile/Geology-Lake-DepthMaps/index.htm.

—Rose-Anna Behr

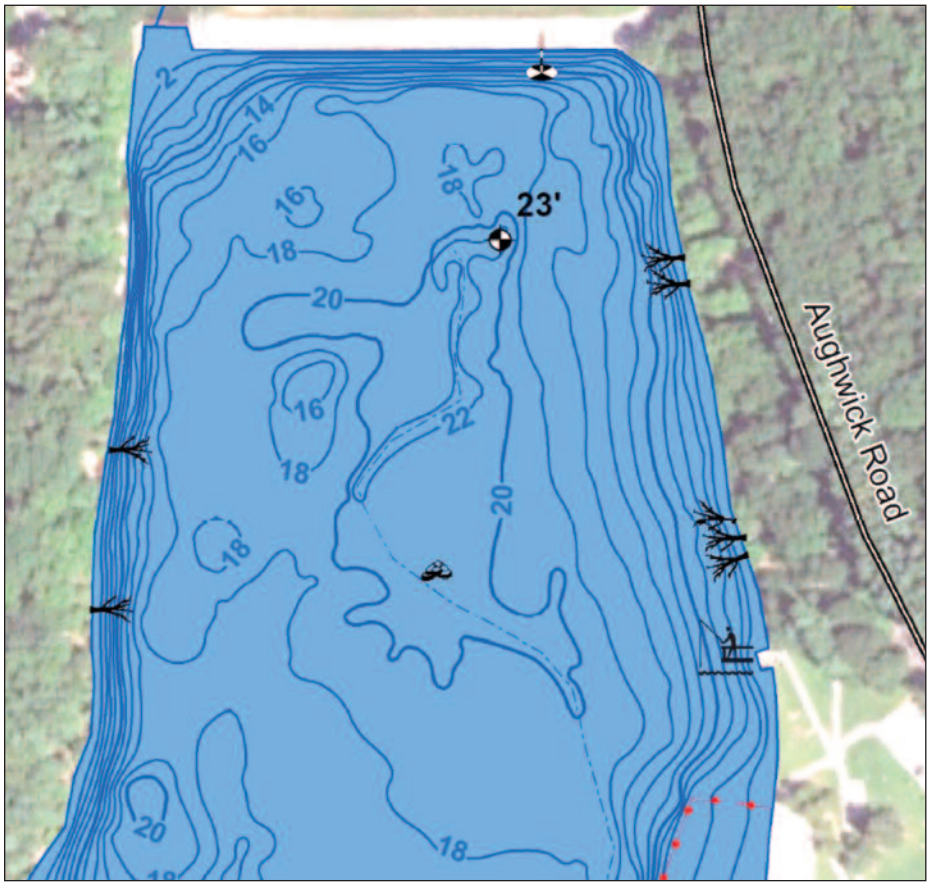
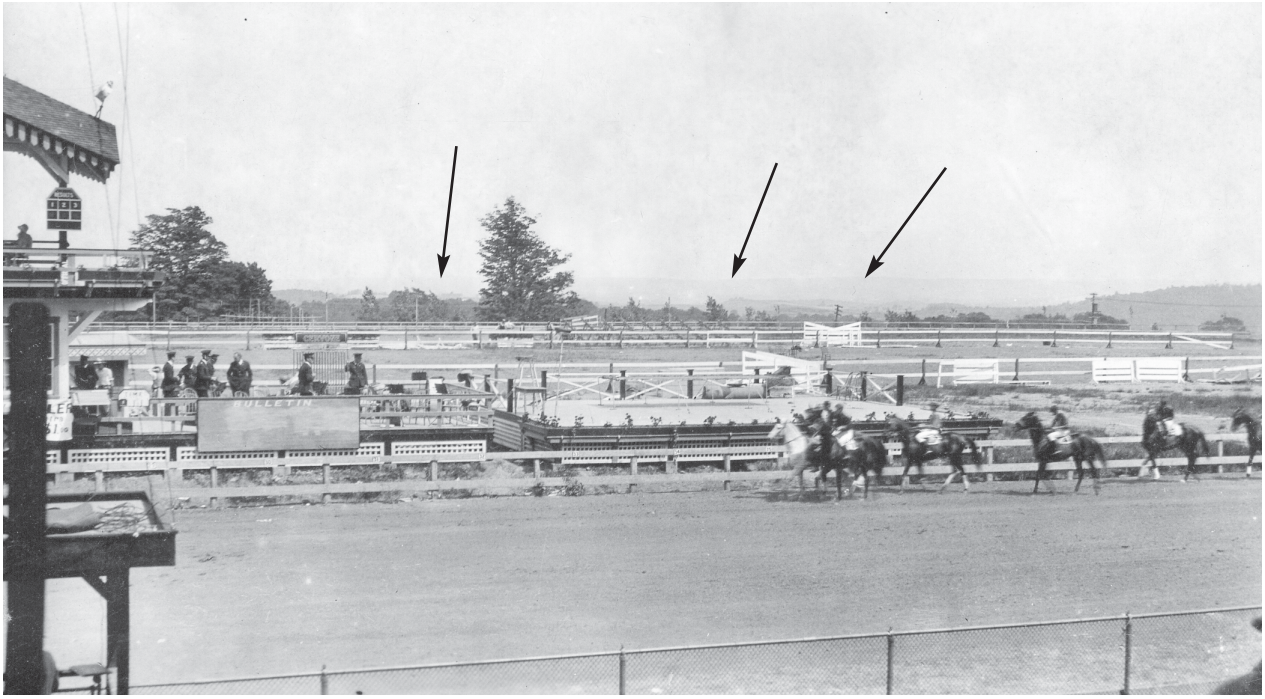


Figure 1. View of Cowans Gap Lake near the dam, showing two-foot contours, the deepest point (23 feet), a lake-level gage (black and white symbol near the top), a fishing pier, downed trees, the edge of the swimming area (red dots), and a placed rock pile.

A LOOK BACK IN TIME



Former State Geologist (from 1919 to 1946) George Ashley enjoyed a horse show and the local geology at the fairgrounds in Ebensburg, Cambria County, perhaps during a break from field mapping. This photograph was taken during the Cambria County Industrial Exposition in July 1927. Ashley described the feature in the background (indicated by arrows) as a peneplain. Photograph provided by Jody Smale, librarian, Pennsylvania Geological Survey.

To see more photographs from the bureau's archives, please visit the library's Historical Photographs Collection page at http://digitalcollections.powerlibrary.org/cdm/search/collection/spgsl-photo.

RECENT PUBLICATIONS

Open-File Miscellaneous Investigations **(July 2016)**

- Water depth of Lake Frances—Nescopeck State Park, Luzerne County, Pennsylvania
- Water depth of Laurel Lake—Pine Grove Furnace State Park, Cumberland County, Pennsylvania

Open-File Miscellaneous Investigation **(June 2016)**

- Water depth of Cowans Gap Lake—Cowans Gap State Park, Fulton County, Pennsylvania

Calling All Authors

Articles pertaining to the geology of Pennsylvania are enthusiastically invited. The following information concerning the content and submission of articles has been abstracted from "Guidelines for Authors," which can been seen in full on our website at www.dcnr.state.pa.us/topogeo/publications/pageolonline/pageoolguide/index.htm.

Pennsylvania Geology is a journal intended for a wide audience, primarily within Pennsylvania, but including many out-of-state readers interested in Pennsylvania's geology, topography, and associated earth science topics. Authors should keep this type of audience in mind when preparing articles.

Feature Articles: All feature articles should be timely, lively, interesting, and well illustrated. The length of a feature article is ideally 5 to 7 pages, including illustrations. Line drawings should be submitted as CorelDraw (v. 9 or above) or Adobe Illustrator (v. 8 or above) files.

Earth Science Teachers' Corner: Articles pertaining to available educational materials, classroom exercises, book reviews, and other geologic topics of interest to earth science educators should be 1 to 2 pages in length and should include illustrations where possible.

Announcements: Announcements of major meetings and conferences pertaining to the geology of Pennsylvania, significant awards received by Pennsylvania geologists, and other pertinent news items may be published in each issue. These announcements should be as brief as possible.

Photographs: Photographs should be submitted as separate files and not embedded in the text of the article.

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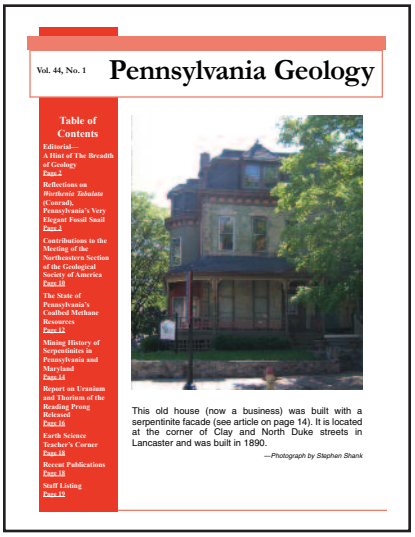
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This old house (now a business) was built with a serpentinite facade (see article on page 14). It is located at the corner of Clay and North Duke streets in Lancaster and was built in 1890.

—Photograph by Stephen Shank

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