Mine Subsidence

Identifying Hazards: Mine Subsidence

Description

According to Galloway and others (2000), "Land subsidence is a gradual settling or sudden sinking of the earth's surface owing to subsurface movement of earth materials. Subsidence is a global problem and, in the United States, more than 17,000 square miles in 45 states, an area roughly the size of New Hampshire and Vermont combined, have been directly affected by subsidence." The most common type of land subsidence in Kentucky, karst subsidence, is discussed in another section of this report. This section deals with the other common type of land subsidence in Kentucky—mine subsidence—which is a human-induced hazard.

Mine subsidence can be described as settlement of the ground surface as a result of readjustments of mine overburden overlying voids created during or after the mining process. These readjustments can be caused by roof falls, pillar failure, pillars sinking into weak floor, coal fires, and other factors (Fig. 4-1). Where underground mines are overlain by a considerable thickness of consolidated rock, subvertical fractures can propagate upward toward the surface, resulting in downward settling of the strata. Alternatively, shallow mines overlain by a thinner rock overburden may collapse, causing overlying soil and unconsolidated sediment to sink into the resulting void. Both processes result in a surface depression that worsens over time. Propagation of fractures and stresses from underground mine collapse leads to vertical displacement (collapse), tilting, horizontal displacement, and strain at the surface (Gray and Bruhn, 1984). Subsidence does not occur above all mines, and potentially adverse impacts of subsidence must be planned for and mitigated in modern mining operations prior to development.

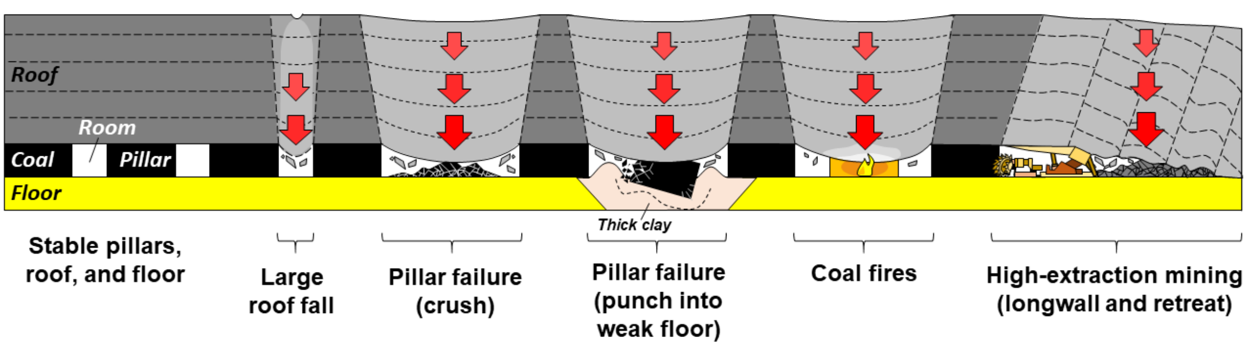

Figure 4-1. Some of the causes of underground mine subsidence. Loss of support in underground mines can create spaces that cannot support the overburden, leading to collapse and, potentially, surface subsidence.

Mine subsidence in Kentucky is most often associated with coal mined in underground mines, but can also be associated with other minerals such as limestone, lead, and zinc mined in the subsurface. Coal-mine subsidence is the dominant type, because significantly more coal has been mined than limestone and vein minerals, and the thin-bedded strata above many coal beds is more susceptible to fracturing and is weaker than thick limestone sequences or limestones containing vein minerals. The U.S. Bureau of Mines estimated that 2 million acres of land has been influenced by coal-mine subsidence, mostly in the eastern United States; in Kentucky, 37,200 acres in urban areas has been estimated to be threatened from coal mine subsidence (Johnson and Miller, 1979).

Hazards and Damage from Mine Subsidence

Subsidence can damage manmade surface structures, modify surface drainage (and result in ponding), and modify groundwater and aquifers (Gray and Bruhn, 1984). The most documented hazards related to mine subsidence are surface cracks and building damage (Fig. 4-2). Subsidence typically causes cracks in foundations, walls, and ceilings, and separation of chimneys, porches, and steps from a structure. In some cases, water, sewer, and gas lines have been broken. Telephone lines and power lines can also be damaged by subsidence (Harper, 1982; Gray and Bruhn, 1984; Cromwell, 2001; Pennsylvania Department of Environmental Protection, 2001; Bauer, 2013; Tonsor and others, 2014). Damage may be localized or more widespread. For example, in Scranton, Pa., $29 million worth of property, including 2,000 homes, 50 commercial and office buildings, two hospitals, and several schools, has been damaged by mine subsidence (Lee and Abel, 1983).

Figure 4-2. Examples of damage to structures from mine subsidence in Madisonville, Ky. Images from Kentucky Geological Survey archives.

Subsidence can also damage roadways and railroads. Between 1995 and 2001, the Ohio Department of Transportation spent $26.6 million to repair mine-subsidence damage to eight highways, including a high-profile case in which part of Interstate 70 collapsed (Hoffman and others, 1999; Crowell, 2001; Ruegsegger and Lefchik, 2004). In Pennsylvania, mine subsidence above an inactive underground mine damaged a segment of railroad, which had to be leveled again and realigned (Pennsylvania Department of Environmental Protection, 2001).

Subsidence depressions and associated fractures may disrupt surface and underground water flow (Fig. 4-3), affecting water supplies and water quality (Lee and Abel, 1983; Booth, 1986; Roth and others, 1990; Harper and Olyphant, 1993; Tonsor and others, 2014). Fracturing and sagging of overburden can alter groundwater flow, affecting wells, springs, and surface streams above or adjacent to subsidence areas (Gray and Bruhn, 1984). Changes in water quality have also been documented in the Illinois and Appalachian coal basins, where subsidence-induced fractures intersected with natural fractures and changed groundwater-flow patterns (Kendorski, 1993; Minns and others, 1995; Zipper and others, 1997; Booth and Bertsch, 1999). Ponding above surface depressions has also been documented; for example, in southern Illinois, ponding above subsidence depressions had an adverse impact on crop yields at some farms (Harper, 1982; Darmody and others, 1989). Since fracturing from mine subsidence does not always reach the surface, its influence on subsurface hydrology may be an even more widespread issue than damage to structures on the surface.

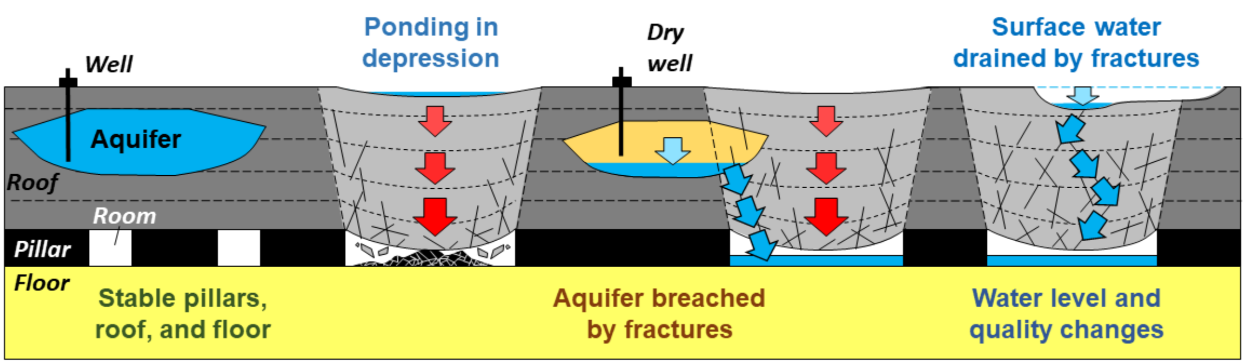

Figure 4-3. Potential mine-subsidence influences on surface water and groundwater.

Methane emissions may also be associated with coal-mine subsidence. A study of subsidence events in Madisonville, Ky., found that large volumes of methane that had collected in underground mines were leaking to the surface through fracture networks caused by mine subsidence (Craft and others, 1986). In 2015, a Walmart in Madisonville had to be shut down for several days because of a water and gas leak that was related to mine subsidence. While trying to determine how deep the mine was below the property, a drilling crew intersected a gas pocket in fractured rock above the old mine works (WFIE, 2015).

Types of Mine Subsidence

Several different types of mine subsidence are known in the Midwestern and Eastern United States. Pit subsidence (also called "sinkhole" and "chimney subsidence") is a localized surface hole or pit that can develop above mines (Fig. 4-4). It most commonly occurs above collapsed rooms or entries in shallow (less than 100 feet deep) room-and-pillar mines. Most roof falls in underground mines result in the collapse of only the immediate roof. Through time, however, under certain conditions, falls may continue upward, in a process referred to as "stoping," and result in sinkhole subsidence at the surface (Aughenbaugh, 1980). Although most commonly encountered above shallow mines, pit subsidence can occur above mines several hundred feet beneath the surface under certain circumstances (Harper, 1982; Lee and Abel, 1983; Gray and Bruhn, 1984; Cromwell, 2001; Bauer, 2013). Pit subsidence is not generally concurrent with mining. A study in Pennsylvania found that more than half of recorded sinkhole subsidence events happened 50 or more years after mining, and a few occurred more than 100 years after mining (Gray and others, 1977; Gray and Bruhn, 1984).

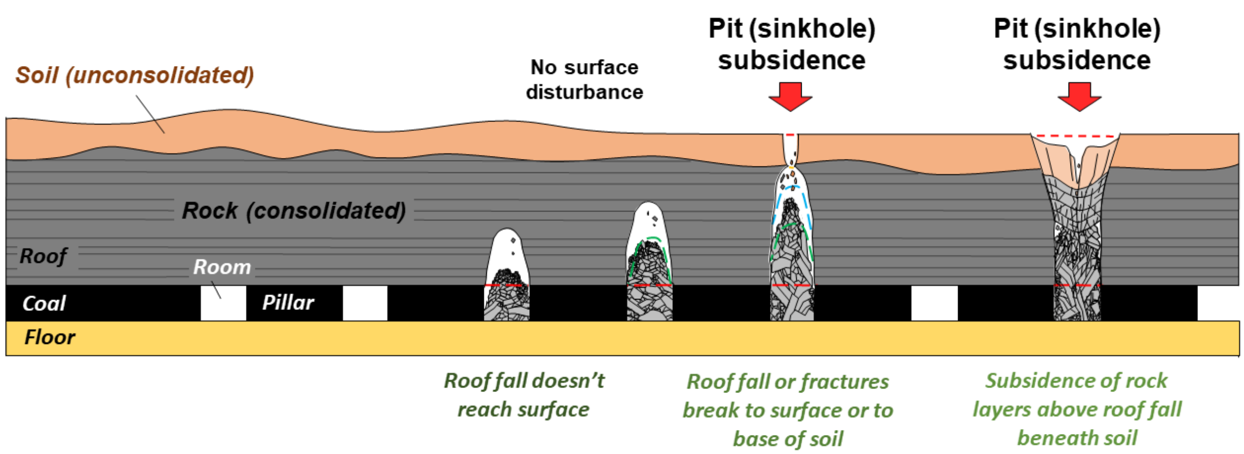

Figure 4-4. Pit (sinkhole) subsidence above an underground coal mine. (Based in part on diagrams in Pennsylvania Department of Environmental Protection, 2017).

Sag or trough subsidence forms gentle, linear depressions over a broad area and is most often caused by the removal or collapse (crushing or foundering) of adjacent coal pillars in room-and-pillar mines or occurs above mines that remove large contiguous volumes of coal, such as longwall and retreat mines (Fig. 4-5). Depressions at the surface may be several hundred feet long and a few hundred feet wide (Harper, 1982; Lee and Abel, 1983; Gray and Bruhn, 1984; Cromwell, 2001; Bauer, 2013). Sag subsidence above longwall mines (which are designed to remove large blocks of coal across long distances) generally occurs as the longwall panel advances or shortly after. Retreat mining practices, which remove pillars when a mine section is abandoned, can similarly result in trough subsidence during or shortly after mining (Gray and Bruhn, 1984).

Because longwall and retreat mines are especially prone to subsidence, the areas of potential impact at the surface are calculated before the mines are permitted, and mining is generally not allowed where it might have an impact on surface structures.

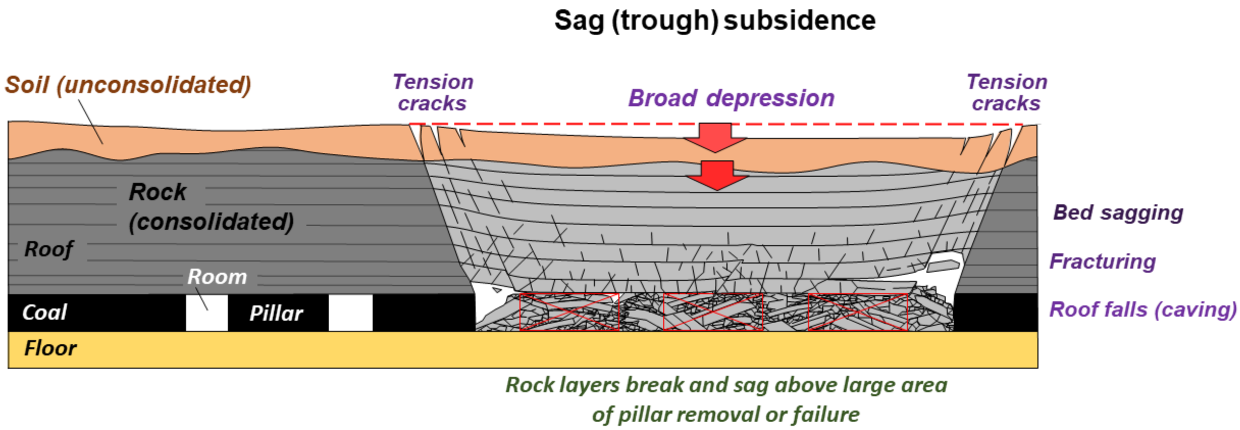

Figure 4-5. Sag (trough) subsidence above an area in which pillars have collapsed or been removed (red boxes at coal level) in an underground mine. See Figure 4-1 for some of the causes of pillar failure. Illustration based in part on diagrams in Pennsylvania Department of Environmental Protection (2017).

Factors Influencing Mine Subsidence

Many factors influence mine subsidence (Fig. 4-6) (Lee and Abel, 1983; Gray and Bruhn, 1984), including:

- Age of mine (historic versus modern)
- Seam thickness (thickness of excavated interval)
- Pillar and entryway dimensions (width of excavations and remaining support)
- Depth to mine (thickness of rock overburden and unconsolidated cover)
- Mine type (room-and-pillar versus longwall or retreat)
- Competency of overburden bedrock (lithology, bedding, rock strength)
- Competency of mine floor
- Surface topography
- In-situ stresses
- Water movement and fluctuation in old mines
- Hydrology of overburden material
- Fractures (natural and manmade) and joints
- Number of superimposed underground mines (or multiseam mines)

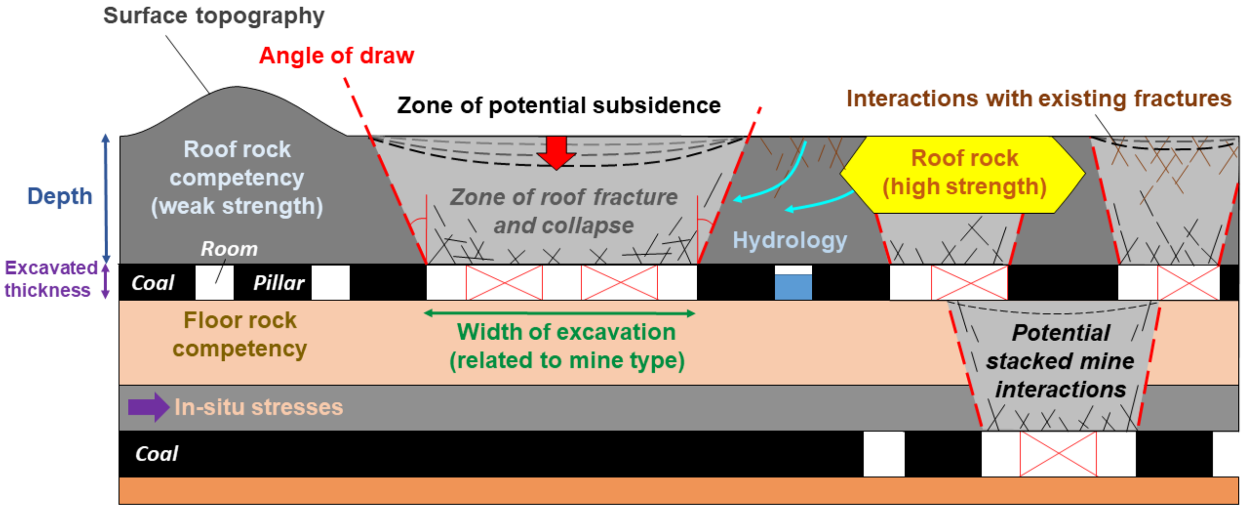

Figure 4-6. Some of the parameters that influence whether underground mine collapses will cause subsidence at the surface. Red boxes at the coal-bed levels are pillars that have been removed or collapsed to create a large unsupported space underground.

Because of the large number of factors and the possibility of other causes for subsidence, each potential subsidence site requires individual assessment to determine whether mining was the cause. In some cases, data are available to assess individual sites; in others, data are more limited. Site-based assessments are not practical for regional hazard evaluations, however. A few critical criteria are discussed in more detail below.

Age of Mine: Modern mines are permitted and designed with subsidence concerns in mind, so are less frequently associated with surface disturbance (Gray and Bruhn, 1984). For site-specific studies, permit data available for all mine maps can be used to determine when mining took place. For this regional assessment, however, the time when mining took place was not assessed because of the large number of mines involved and incomplete recording of permit numbers in the source data.

Depth: The potential for mine subsidence to reach the surface is greatest above shallow underground mines, so it might be possible in the future to include shallow mines as part of a risk assessment, or assess risk potential by depth. Kentucky does not list permitted underground mines by their depth, however, and estimating the overburden above underground mines for a regional assessment would require site-by-site evaluation or digitization of structural contours for all underground mines to be compared with surface topography; this was not within the scope of this assessment. Also, depth is more complicated in the variable topography of the Eastern Kentucky Coal Field compared to that of the Western Kentucky Coal Field.

Width and Shape of Mine Void: Pillar and entry width vary in different mines, and were more variable in historic mines. For regional assessments, measuring the width and height of the extracted interval of individual mines is not practical, but *critical width* of extraction can be combined with *mined thickness* and a *coefficient related to mine type* to predict whether subsidence will reach the surface. The *width/depth ratio* is the width of extraction divided by the depth of the seam beneath the surface. The deeper the seam, the wider the area of extraction (or collapse) needed to reach the surface.

Another variable, the *angle of draw,* is an inclined line connecting the edge of the mined area with the limit of the surface disturbance. Values for the angle of draw range from 12 to 26° in the Illinois and Appalachian Basins (Gray and Bruhn, 1984). These variables cannot be reasonably assessed in a regional study, although they are assessed in modern mines prior to mining and in site investigations of subsidence events.

Mine Type: High-extraction mining methods such as longwall and retreat mining have a higher potential for surface subsidence than room-and-pillar mining (Gray and Bruhn, 1984). Modern mines in which high-extraction methods are planned must have subsidence potential and likely areas of impact calculated prior to mining. Permits are not generally given for these mining methods beneath population centers, roads, railways, and other susceptible structures. There are few longwall mines in Kentucky, and all are relatively modern mines. There are more retreat mines than longwall mines in Kentucky, but identifying them was not within the scope of this regional assessment.

Geologic and Hydrologic Factors: Rock type, bedding, rock strength, thickness and strength of underclays, fractures, joints, in-situ stresses, and hydrologic factors are all critical to site-specific evaluations and vary, even sometimes within a mine. Core data are usually required to assess these factors, which was beyond the scope of this study.

Multiseam Mining or Stacked Underground Mines: Considering that a single mine can be associated with surface subsidence, then stacked underground mines might have even more potential for propagating subsidence to the surface. Numerous studies have investigated the potential for ground motion and subsidence related to mining above or beneath a previously mined seam (Hasley, 1951; Haycocks and others, 1983; Chekan and others, 1986; Chekan and Listak, 1993; Mark, 2006). Complex stress interactions between mines at different levels in the same area are related to many factors including depth between mines, succession of mining (overmining versus undermining), roof geology (weak versus strong), and pillar strength (Mark, 2007; Mark and others, 2007). Site-specific data on these factors can lead to estimations of the critical distance between mines needed to prevent subsidence into the overlying mine, and potentially with time, to the surface, but this type of evaluation was beyond the scope of this study. In eastern Kentucky, many drift mines into hillsides are at different levels in different coal beds. Likewise, in western Kentucky, both the Herrin (W. Ky. No. 11) and Springfield (W. Ky. No. 9) coal beds were mined beneath the surface in the same area.

Profiling Hazards: Mine Subsidence

<u>Location</u>

Because the focus of this assessment is a regional understanding of subsidence related to underground coal mines, the hazard in Kentucky is limited to the eastern and western coal fields. A site-by-site investigation of known and possible subsidence localities is not feasible for the present study; nor is a regional assessment of depths to mines, individual mine plans, or detailed understanding of overburden layering and strength. For a regional assessment, however, the extent of abandoned and active underground mines in Kentucky is reasonably well known; therefore, specific areas of potential subsidence can be determined where there is a known underground mine at some depth beneath the surface. Mine location can further qualify the assessment. Figure 4-7 shows the distribution of underground mines in the Eastern and Western Kentucky Coal Fields. The mined areas cover about 800,000 acres of the land surface of Kentucky, or about 3 percent of the land surface.

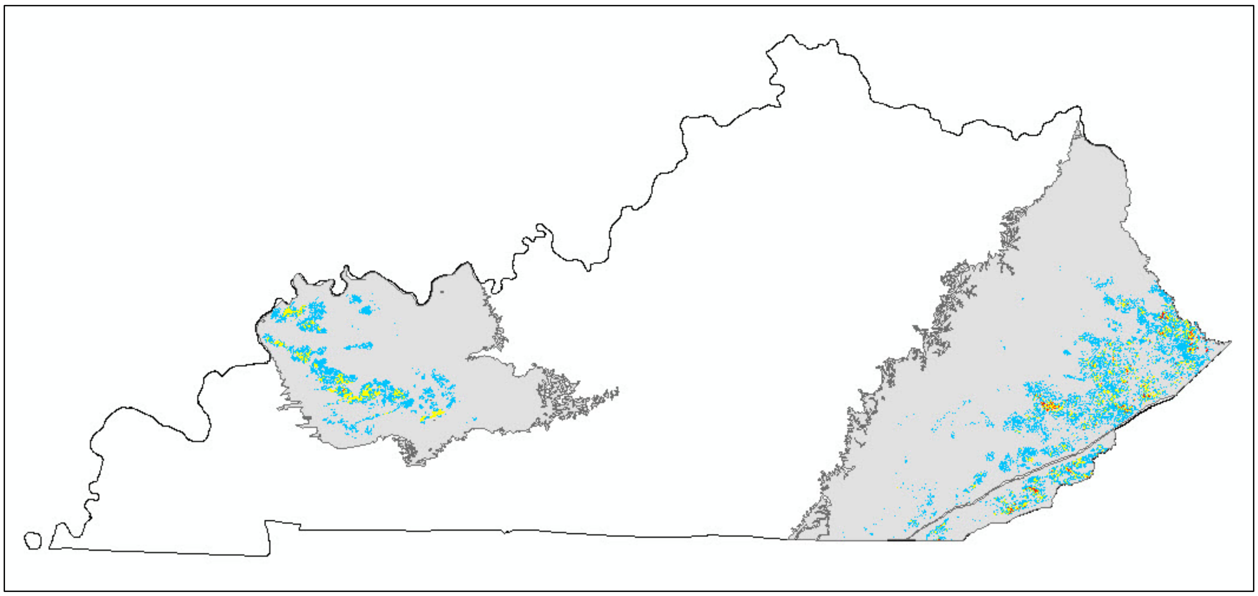

Figure 4-7. Areas of the Eastern and Western Kentucky Coal Fields underlain by underground coal mines. Coal-fields are outlined in gray and colored areas depict the number of mines stacked vertically at a location (up to six). Blue indicates one coal mine, yellow indicates two coal mines, and other colors indicate the infrequent occurrence of three or more associated mines. Underground mines have not been cataloged north of 38° latitude in eastern Kentucky, which would include Boyd, Carter, Greenup, Elliott, and parts of Lawrence Counties.

Extent and Scale of Individual Hazards

Mine subsidence is not considered to be a high-level hazard because it generally occurs slowly and individual events are typically not temporally or spatially linked to other events. Subsidence usually affects individual structures, and in many cases, the damage can be mitigated. No injuries or deaths have been reported in conjunction with mine subsidence in Kentucky. No single government agency in Kentucky tracks the annual costs to remediate damage from mine subsidence, although the Kentucky Division of Abandoned Mine Lands, U.S. Mine Safety and Health Administration, and U.S. Office of Surface Mining Reclamation and Enforcement investigate mine-subsidence claims.

Mine subsidence may have an impact on transportation routes and structures by causing pavement surfaces to fail or weakening structures. Kentucky Transportation Cabinet engineers are aware of the risk and include mitigation strategies in construction designs to avoid future problems. Common strategies are moving the alignment of roads to avoid known shallow, underground mines and grouting shallow mine openings near or beneath planned roadways.

Although most mine subsidence occurs slowly and damage and hazards can be addressed in time to prevent human injury or death, in some situations mine subsidence could result in a catastrophe. On Oct. 11, 2000, more than 300 million gallons of water and slurry broke through the bottom of a slurry impoundment in Martin County, Ky., into an adjacent underground mine. The slurry passed through the mine into two different creeks, then discharged into Tug Fork (U.S. Mine Safety and Health Administration, 2001; National Research Council, 2002; U.S. Office of Surface Mining Reclamation and Enforcement, 2011). Fortunately, no lives were lost, but the sudden discharge of large volumes of water and sediment damaged homes and property, and adversely affected six public water intakes and raised concerns about the safety of slurry impoundments. The cost of cleanup was more than $56 million (U.S. Mine Safety and Health Administration, 2001; U.S. Office of Surface Mining Reclamation and Enforcement, 2011). Although the breakthrough at the Martin County pond does not appear to have been caused by mine subsidence (U.S. Mine Safety and Health Administration, 2001; Hagerty, and Curini, 2004; U.S. Office of Surface Mining Reclamation and Enforcement, 2011), it is an example of how mine subsidence might lead to a sudden, widespread, catastrophic hazard. In fact, the U.S. Office of Surface Mining Reclamation and Enforcement (2011) concluded that impoundment breakthroughs could happen through four mechanisms, one of which was mine-subsidence induced fractures and sinkholes. Michael and others (2010) noted that pillar failure in deep mines, which themselves might be too deep to form subsidence sinkholes or cracks at the surface, could destabilize shallower mine barriers and thereby result in subsidence beneath overlying slurry ponds.

FEMA regulations require that before an impoundment is constructed, the potential danger posed by mines, based largely on downstream population in the event of an impoundment failure or breakthrough, be assessed. Since 2001, additional constraints based on proximity to underground mines are also factored in (U.S. Mine Safety and Health Administration, 2010). Assessing potential hazards based on proximity to population does not mean an impoundment is unsafe; it just means that the closer a mine is to a population center, the greater the potential for damage and injury if something happens. The assigned hazard ranking can be used to determine the need for stricter design and monitoring criteria based on potential danger (Interagency Committee on Dam Safety, 2004). A similar methodology can be applied to regional assessments of mine-subsidence potential.

Previous Occurrences in Kentucky

There have been numerous reports of subsidence in both of Kentucky's coal fields, although more have been reported in western than eastern Kentucky. Perhaps the most widespread are in Madisonville (western Kentucky), where individual buildings, housing developments, and parts of a shopping mall have required extensive repair or relocation because of mine subsidence, which began in the late 1970s and 1980s (Fig. 4-8). The U.S. Office of Surface Mining Reclamation and Enforcement investigated subsidence in the Madisonville area to determine its cause and help mitigate future subsidence. The investigation collected historical data, recorded subsidence damage, conducted subsurface drilling, and inspected abandoned mines 200 to 280 feet beneath the surface using borehole cameras. Pillar crushing and roof collapse in shallow, flooded mines in the Herrin (W. Ky. No. 11) coal were found to be the cause of subsidence. Thick, low-strength underclay floors may also have contributed to pillar failure (McKin and Shakoor, 1985; Craft and others, 1986). Subsidence continues to the present day.

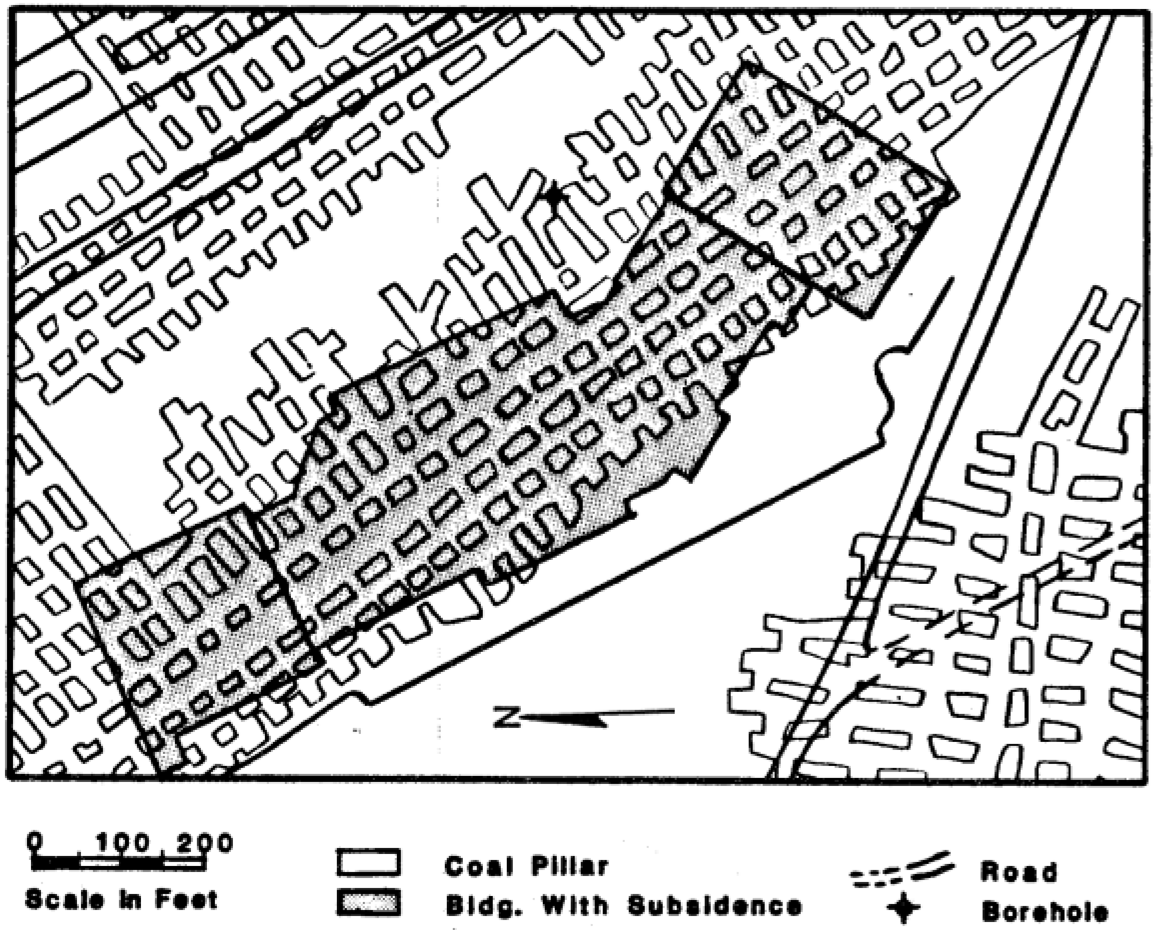

Figure 4-8. Diagram of a shopping mall and parking area in Madisonville, Ky., above an underground coal mine that was damaged by subsidence (from Craft and others, 1986, Fig. 13).The mine was 151 feet beneath the mall.

The only public listings of mine-subsidence occurrences in Kentucky are from the investigating agencies. The U.S. Office of Surface Mining Reclamation and Enforcement investigates some reported subsidence events, and compiles the locations in a database. Their list of 310 historical investigations includes many sites that were determined to be unrelated to mine subsidence, however. The Kentucky Division of Abandoned Mine Lands also investigates reports of subsidence related to mining, and has identified 428 project areas from 1981 to present (the Division defines abandoned mine lands as “areas affected by coal mining that ceased operation prior to May 18, 1982, on which no person or entity has any continuing reclamation responsibility under federal or state law” [Kentucky Division of Abandoned Mine Lands, 2016, p. 1]). But in this assessment, we did not limit subsidence to mines meeting this criteria. Both of these inventories contain locations that were identified during a research investigation conducted by the Kentucky Geological Survey between 1985 and 1987. The KGS study inspected 523 sites in five western Kentucky counties and 206 sites in Boyd County of eastern Kentucky.

Because all of these data lack reporting dates and details about the investigations, determining the frequency of occurrence of subsidence events and the duration of investigations is difficult. Each year, Kentucky receives an Annual Abandoned Mine Land grant with a three-year lifespan that totals approximately $13.5 to $14 million. An average of 25 to 35 reclamation projects are funded with this grant each year, and costs for the projects vary from a few thousand dollars to several million dollars. According to Kentucky Abandoned Mine Lands officials, subsidence investigations typically constitute less than 5 to 10 percent of their annual project funds. Based on these anecdotal reports, mine subsidence is believed to have a relatively low frequency of occurrence in Kentucky. Kentucky does not track the specific costs related to mine subsidence.

Assessing Vulnerability by Jurisdiction: Mine Subsidence

Municipalities

Although mine subsidence can occur anywhere there are underlying coal mines, one manner to broadly assess the relative potential risk from mine subsidence without site-based evaluations is to assess the proximity of subsurface mines to concentrations of buildings or population centers at the surface. This methodology focuses on incorporated municipal areas because this is where the most damage and greatest costs can occur. Most of Kentucky's coal fields are in rural areas with agricultural or forested land use, but several towns and municipalities are located in areas of historical mining.

To assess hazard potential for municipalities, a map of all known underground mines was prepared by vertically aggregating mined-out areas. Mined areas were obtained from the website minemaps.ky.gov in 2014, and each coal-bed layer was reviewed to differentiate surface from underground mines. After surface-mine areas were removed, successive beds were merged so that the number of coincident mine areas could be tabulated. The outlines were converted to a grid format with 100-foot cell dimensions. Each cell records the number of superimposed mines. For this assessment, we inferred that there may be a greater potential for vertical fracture propagation and consequent subsidence in areas underlain by multiple mines than areas underlain by a single mine at depth. Multiple mines have greater potential to have complex stress interactions beneath the surface. Previous reports have shown that where multiple mines are stacked beneath the surface, fractures can propagate between mines or interact with natural fractures (Mark and others, 2007). Over time, under certain conditions, these fractures could lead to surface disturbance.

The risk of mine subsidence was evaluated by calculating the percentage of each municipal area underlain by one or more mines, estimating the density of buildings overlying the mines using aerial photography, and tabulating the number of Office of Surface Mining Reclamation and Enforcement and Abandoned Mine Lands projects coinciding with mined areas. Municipalities were evaluated by each factor, and a ranking of the most vulnerable cities was produced. Figure 4-10 shows a sample of data for the method. Municipalities with a high to moderate risk for future subsidence are listed in Table 4-1.

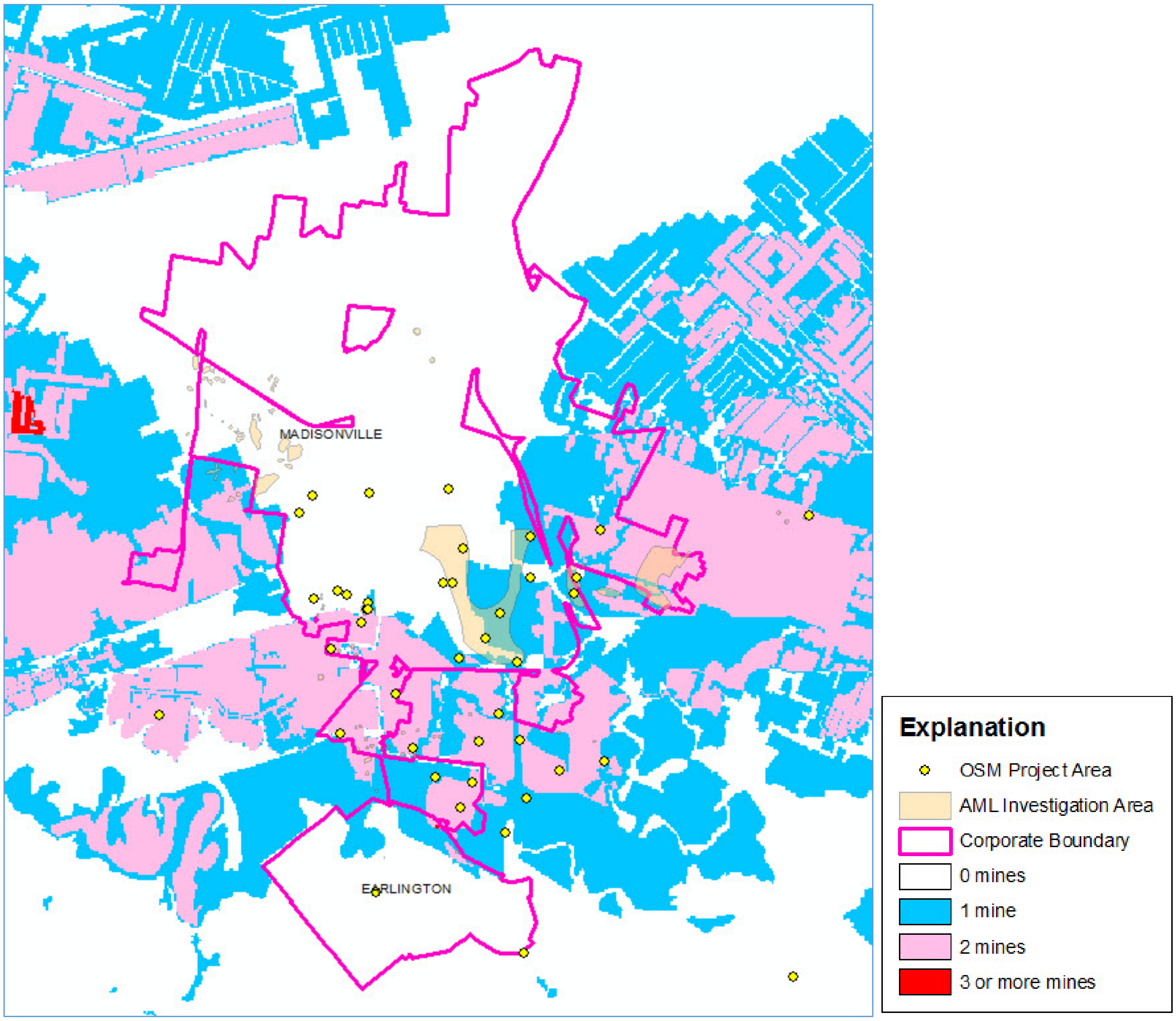

Figure 4-10. Subsidence assessment data for part of Madisonville in western Kentucky.

Data for all municipalities in Table 4-1, including versions with aerial imagery, are available in the Appendix of this section.

Table 4-1. Municipalities with moderate to high risk of future mine subsidence based on proximity to mines and known historic occurrences. The risk assessment does not mean high damage or moderate damage will occur, but that there are more mines beneath the surface in those areas or there is a history of subsidence in those areas, which indicates a higher level of risk.

Name	Coal Field	Risk[1]
Providence	Western	High
Madisonville	Western	High
Powderly	Western	High
Drakesboro	Western	High
Dawson Springs	Western	High
Uniontown	Western	High
Wheatcroft	Western	High
Waverly	Western	High
Morganfield	Western	High
Central City	Western	Moderate
Ashland	Eastern	High
Hazard	Eastern	Moderate
Jenkins	Eastern	Moderate

[1] Qualitative assessment of density of buildings coinciding with mined areas.

Airports

Both the Eastern and Western Kentucky Coal Fields have small regional public airports with paved tarmacs. Each of these facilities was compared to the underground-mine layer to assess whether there might be a risk of subsidence for the runways. Only two airport runways have some area underlain by mines—Hatcher Field in Pike County and Big Sandy Regional in Martin County. There is no indication that there have been any issues with subsidence at these facilities.

Pipelines, Railroads, and Roadways

Modern mines typically need special permits to mine under state or federal highways, and plans must be in place to limit potential surface disturbance beneath pipelines, railroads, and roadways. Similarly, when new roads are developed in Kentucky, the Department of Transportation plans for subsidence and avoids building roads above shallow mines, or grouts mine voids near new roads. Secondary roads and parking lots have been damaged by historic mine subsidence in Madisonville, Ky., but we are unaware of any reports of damage to a pipeline, railroad, or major state or federal highway in Kentucky from underground-mine subsidence.

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APPENDIX

Subsidence assessment data maps for municipalities in Table 4-1

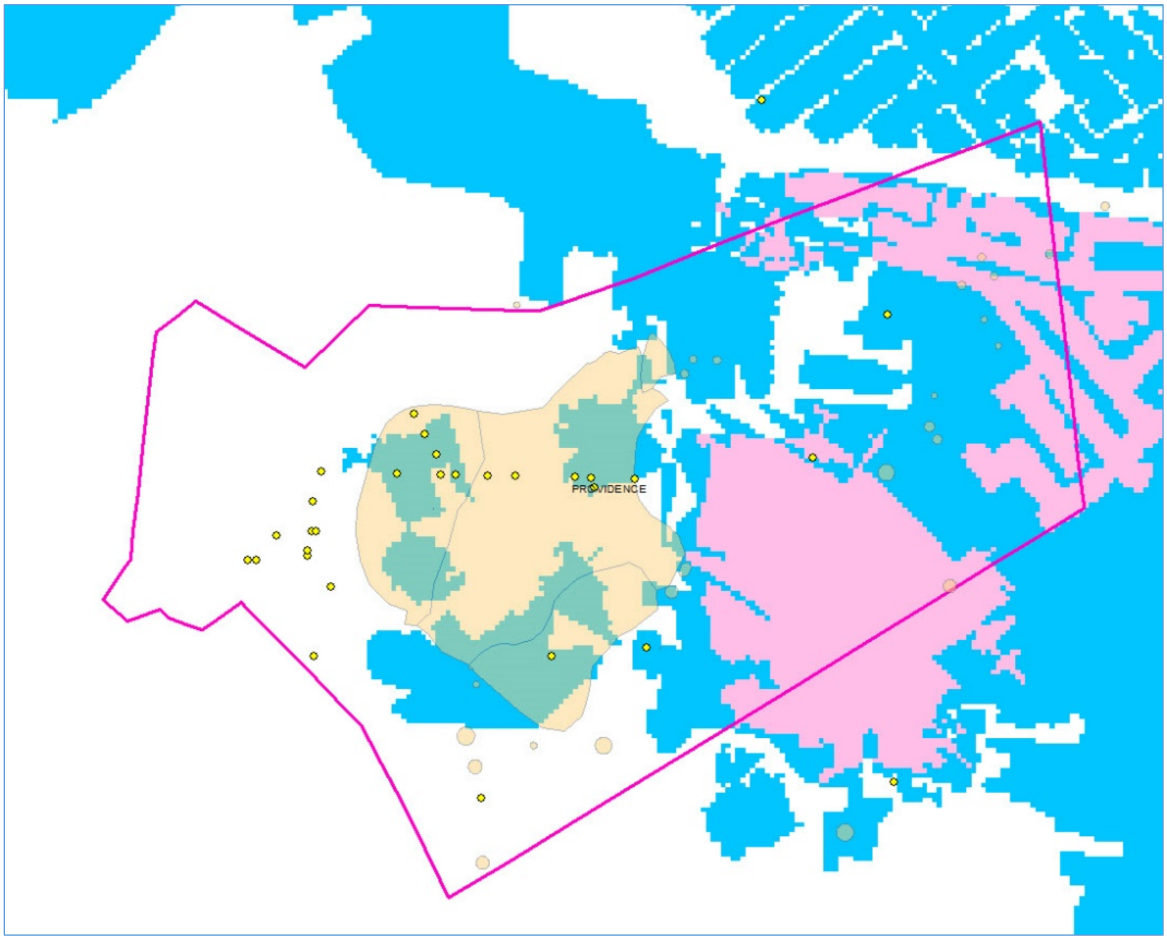
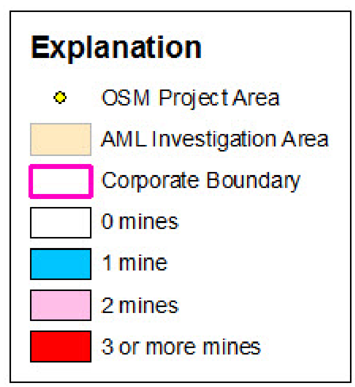


Figure 4-11a. Subsidence assessment data for part of Providence in western Kentucky



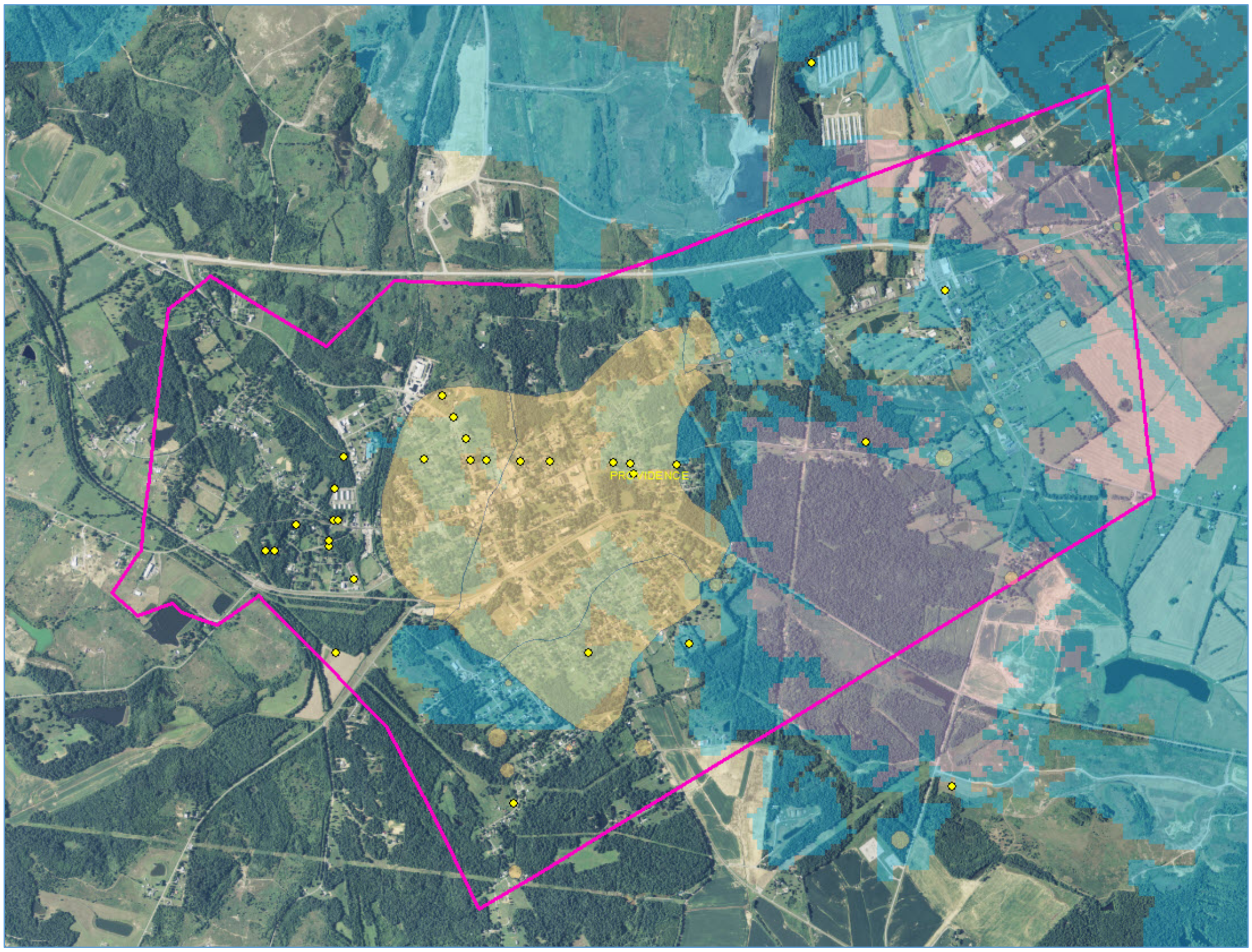
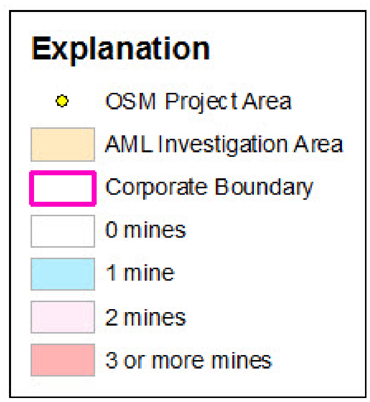


Figure 4-11b. Subsidence assessment data for part of Providence in western Kentucky, with aerial imagery



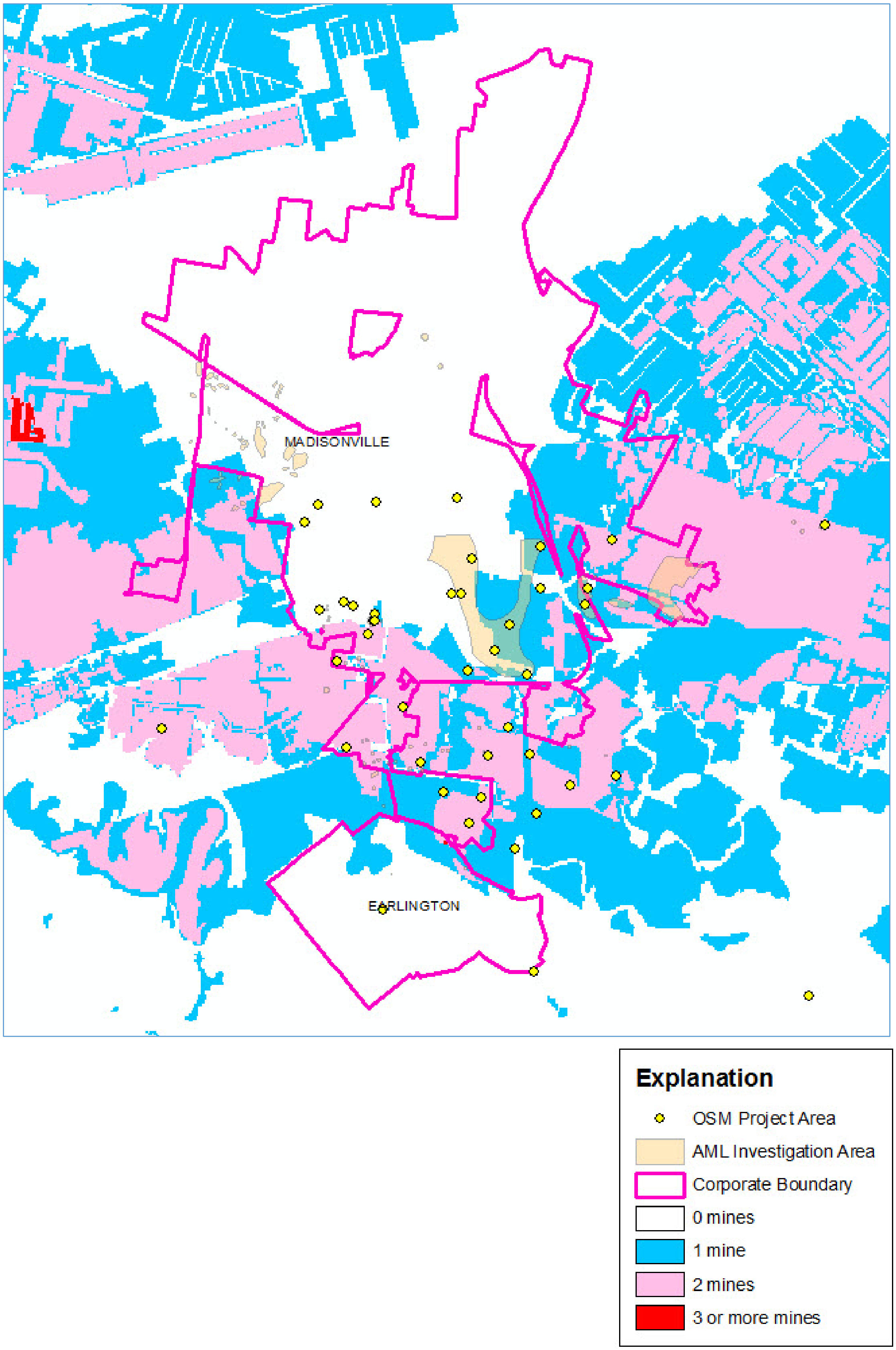

MADISONVILLE
EARLINGTON
Explanation
OSM Project Area
AML Investigation Area
Corporate Boundary
0 mines
1 mine
2 mines
3 or more mines

Figure 4-12a. Subsidence assessment data for part of Madisonville in western Kentucky

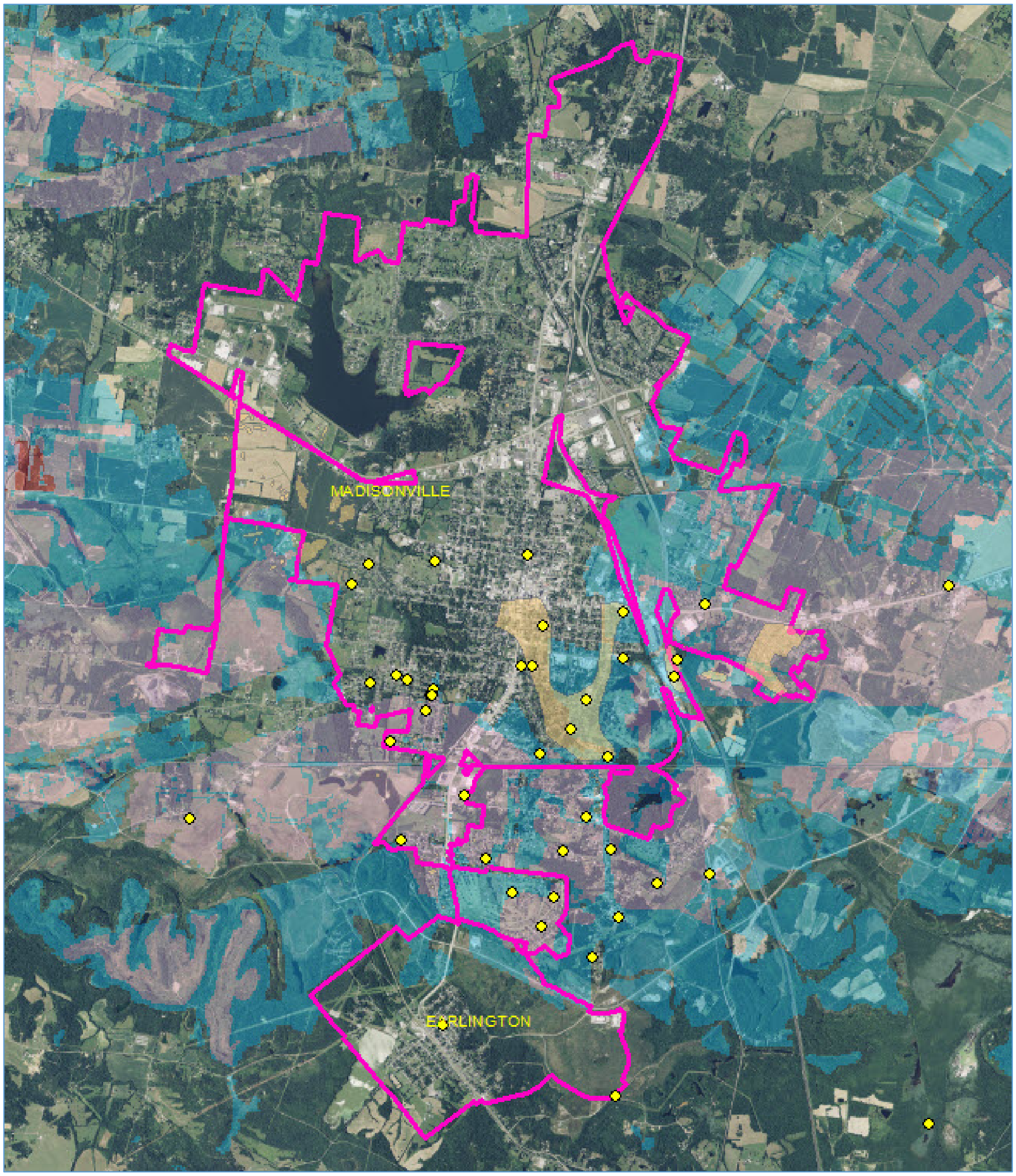

MADISONVILLE
EARLINGTON

Figure 4-12b. Subsidence assessment data for part of Madisonville in western Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

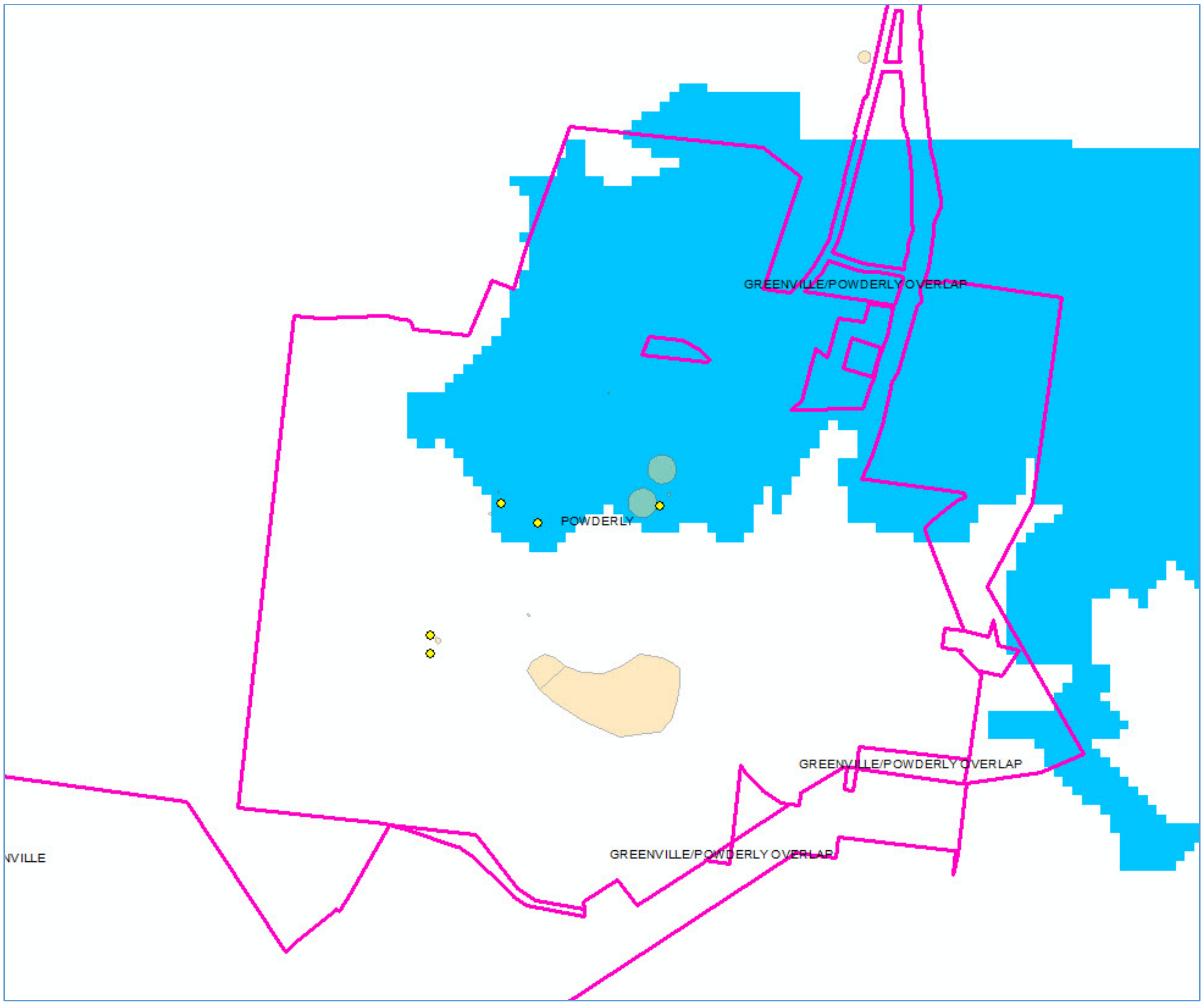
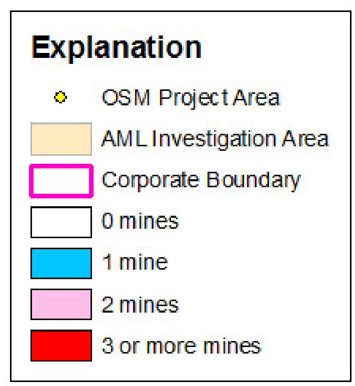


Figure 4-13a. Subsidence assessment data for part of Powderly in western Kentucky



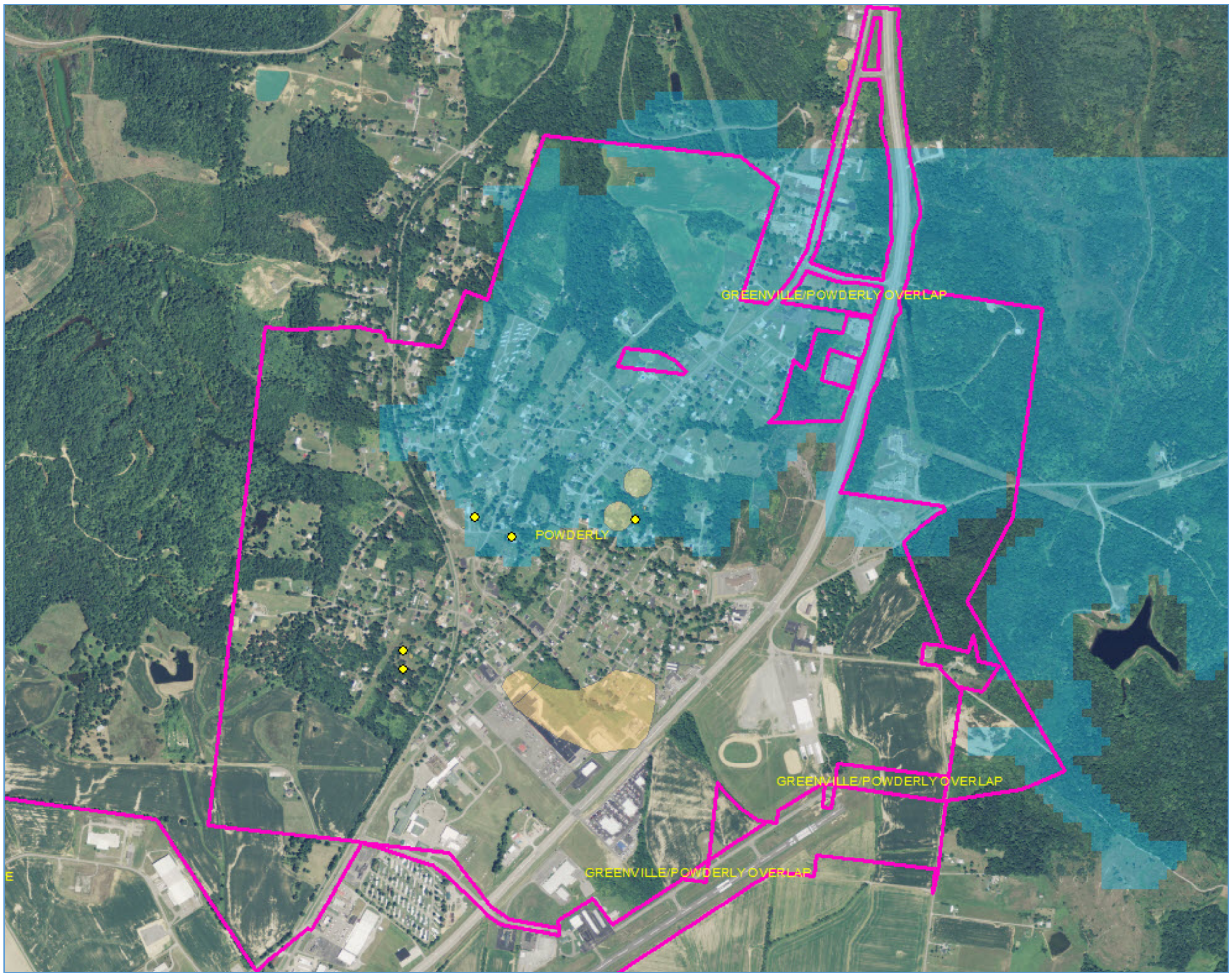
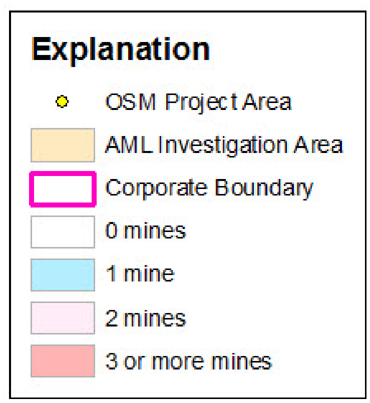


Figure 4-13b. Subsidence assessment data for part of Powderly in western Kentucky, with aerial imagery



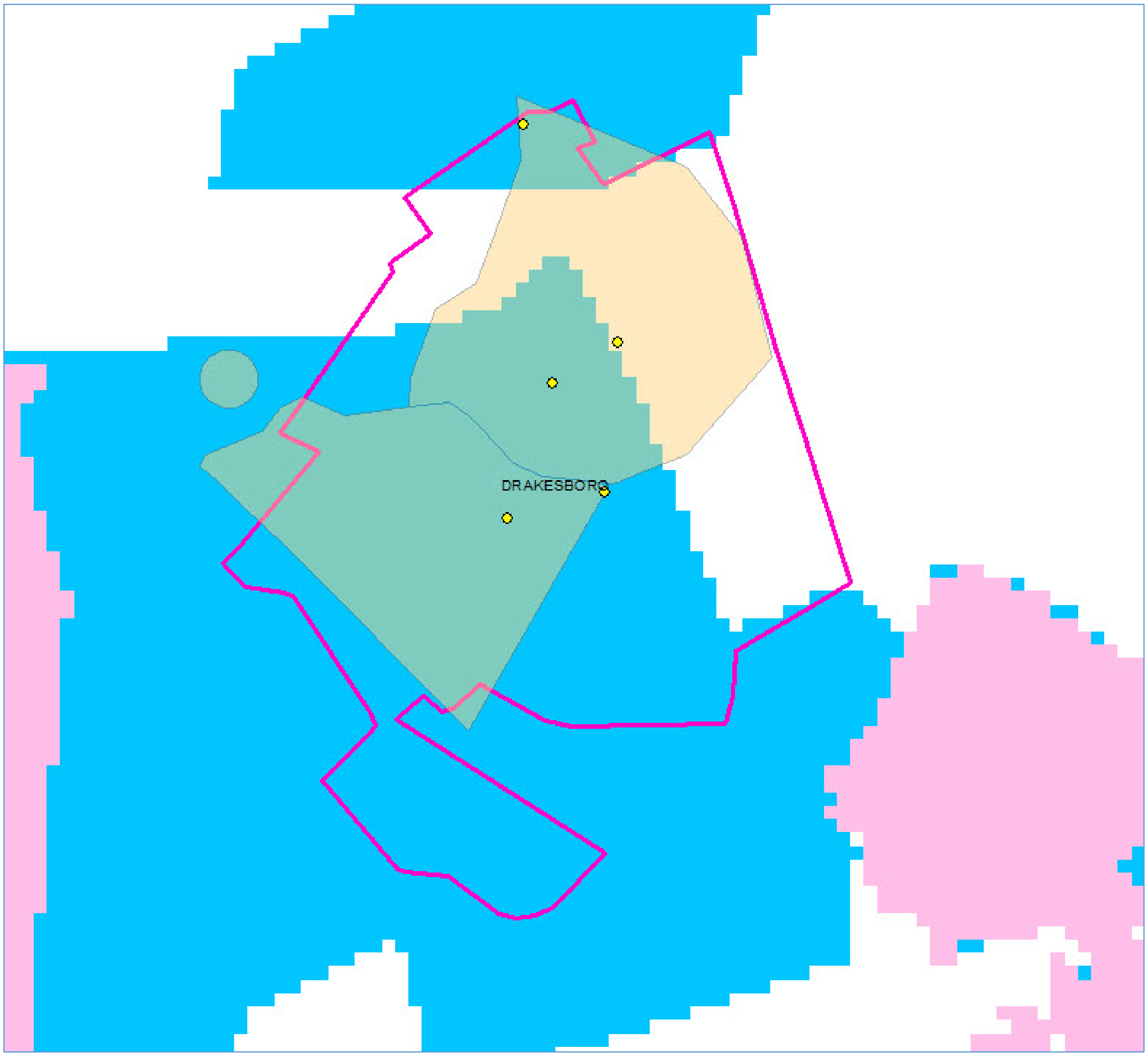


Figure 4-14a. Subsidence assessment data for part of Drakesboro in western Kentucky

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

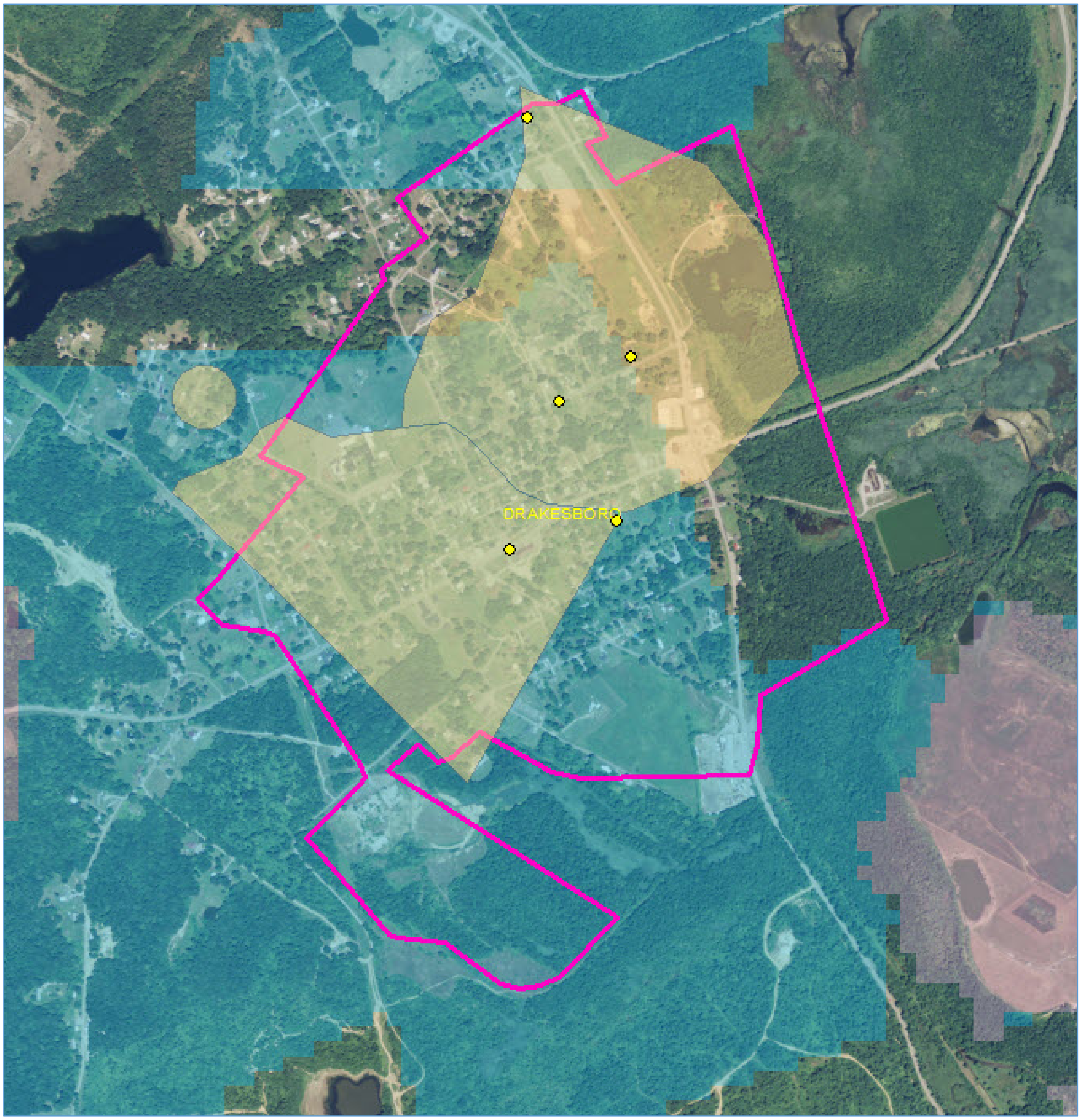
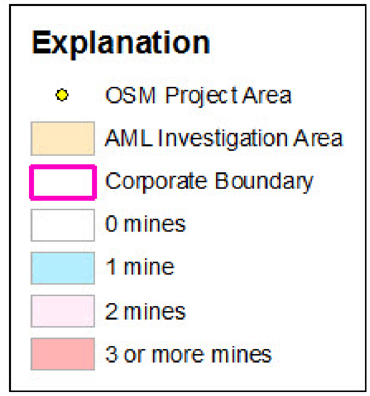

DRAKESBORO

Figure 4-14b. Subsidence assessment data for part of Drakesboro in western Kentucky, with aerial imagery



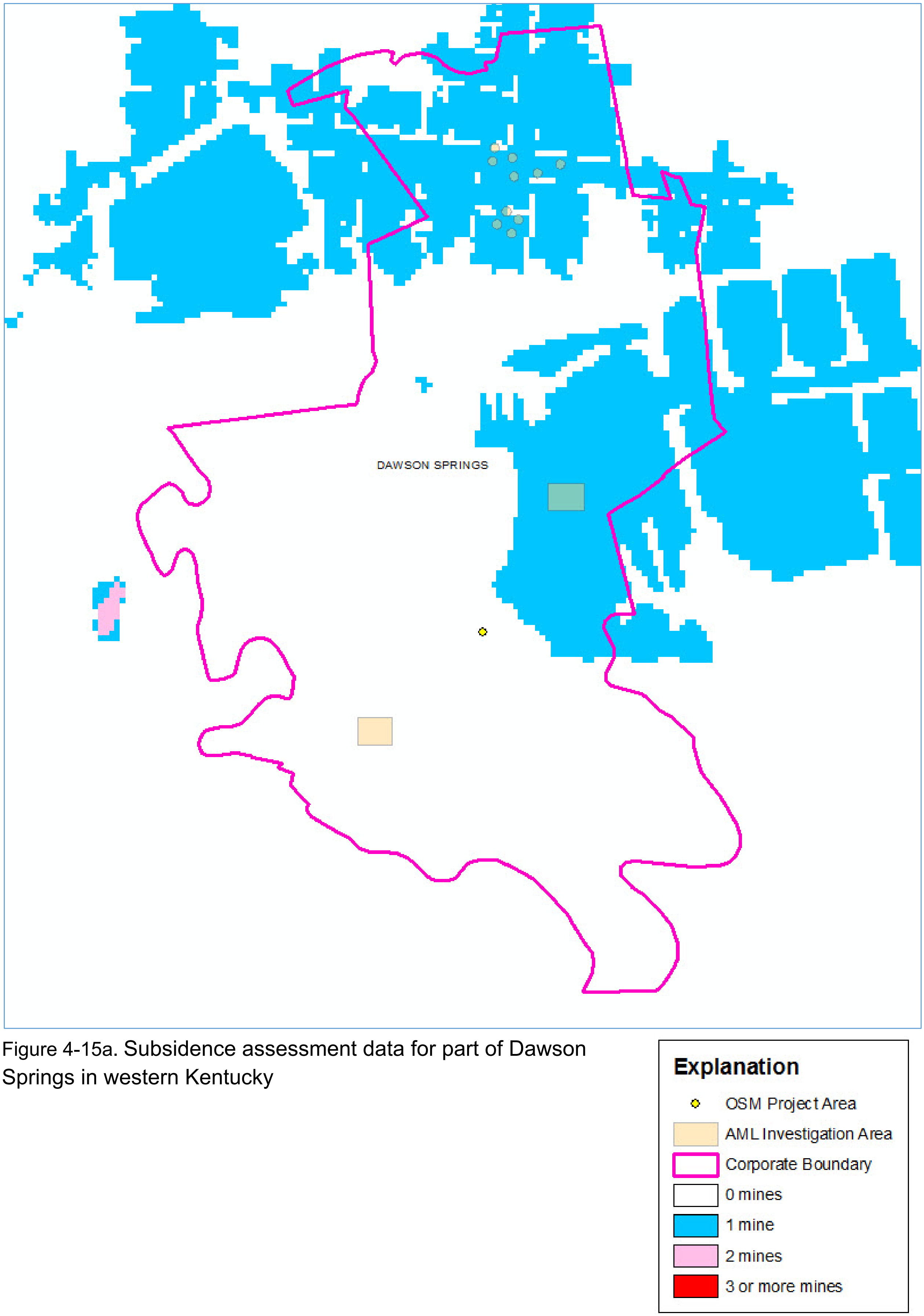


Figure 4-15a. Subsidence assessment data for part of Dawson Springs in western Kentucky

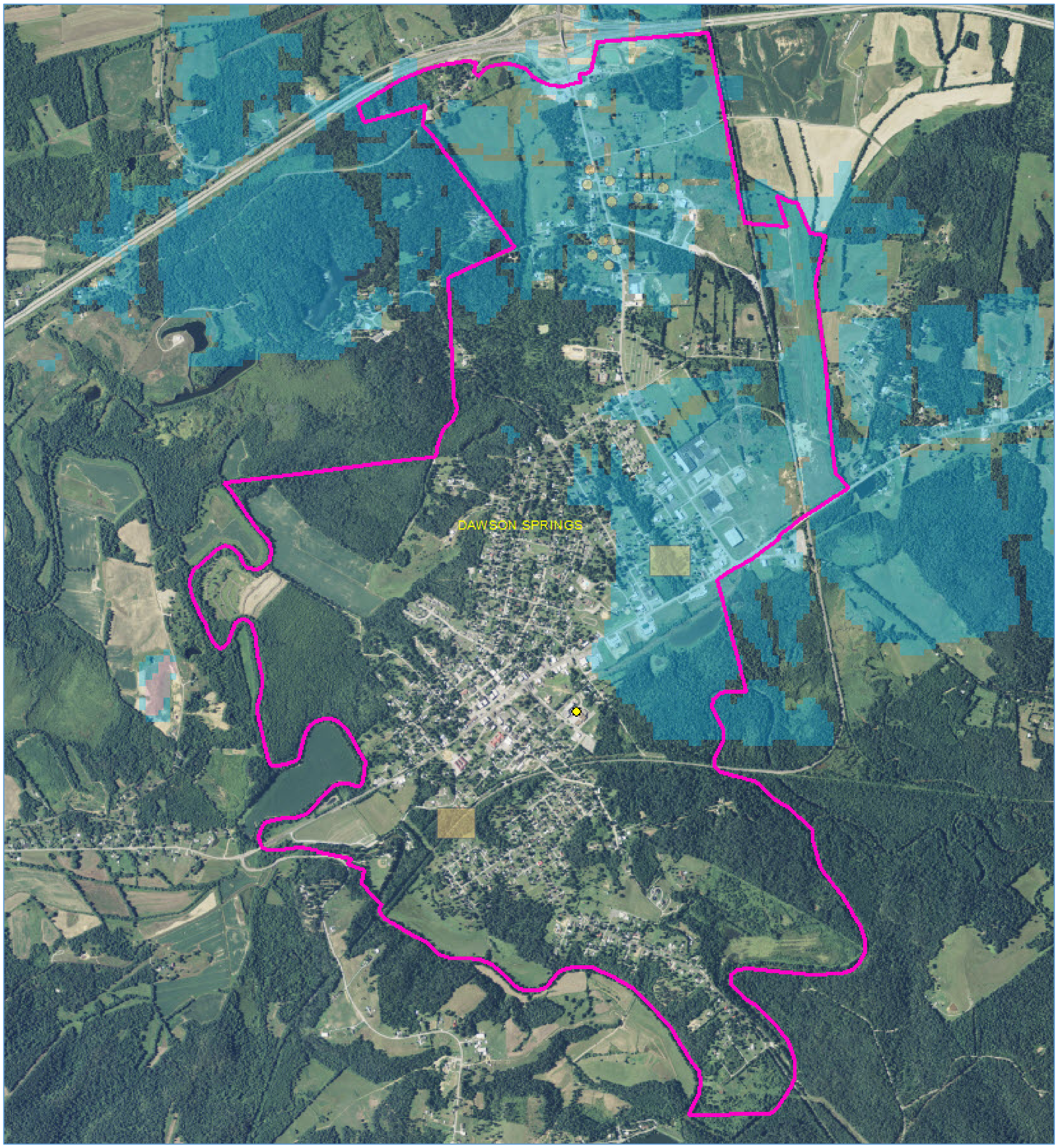
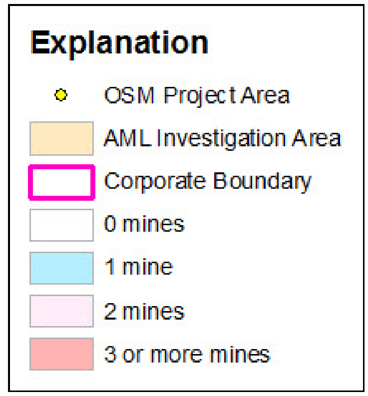

DAWSON SPRINGS

Figure 4-15b. Subsidence assessment data for part of Dawson Springs in western Kentucky, with aerial imagery



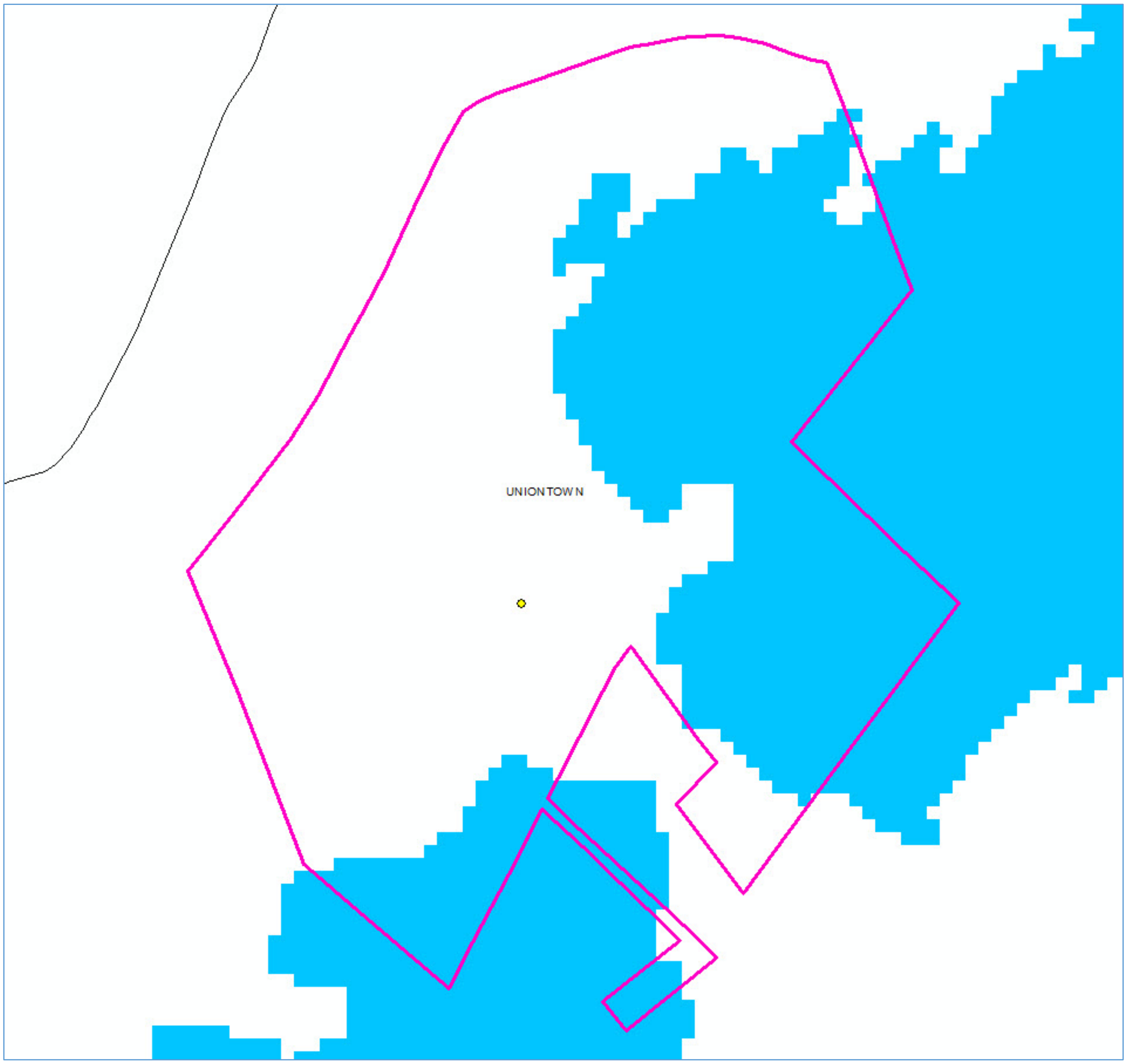


Figure 4-16a. Subsidence assessment data for part of Uniontown in western Kentucky

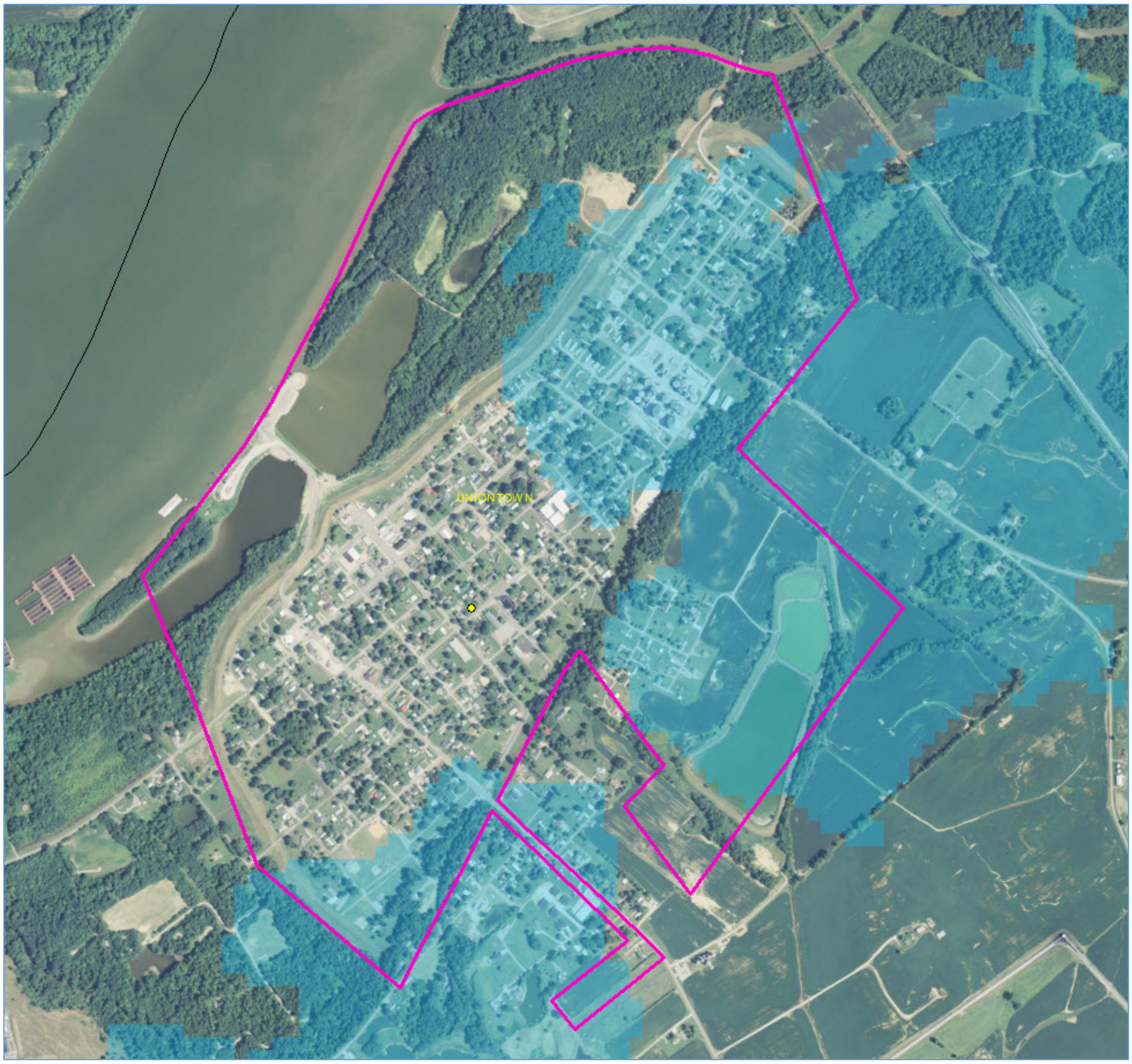


Figure 4-16b. Subsidence assessment data for part of Uniontown in western Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

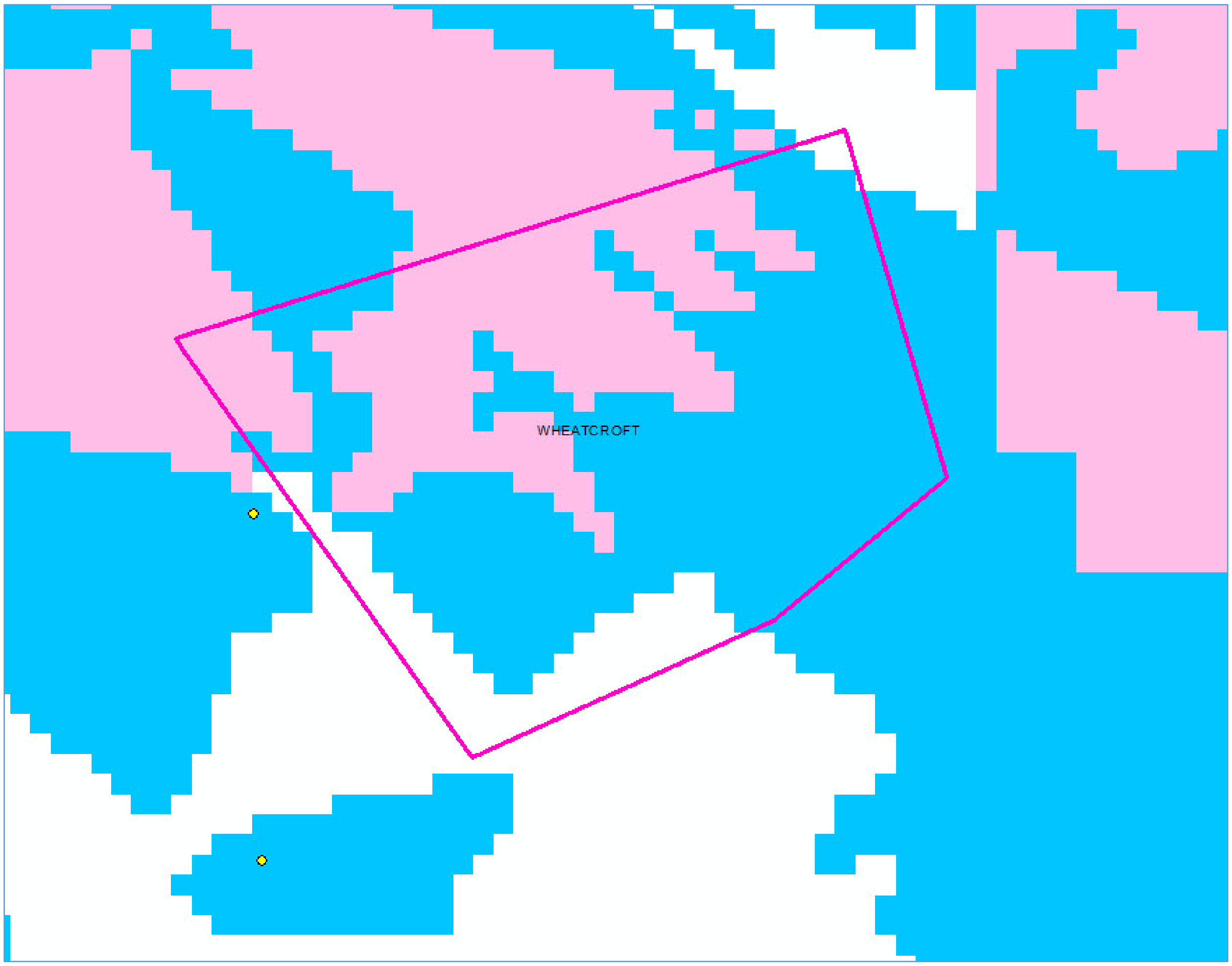
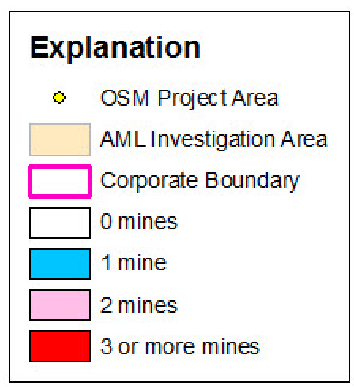


Figure 4-17a. Subsidence assessment data for part of Wheatcroft in western Kentucky



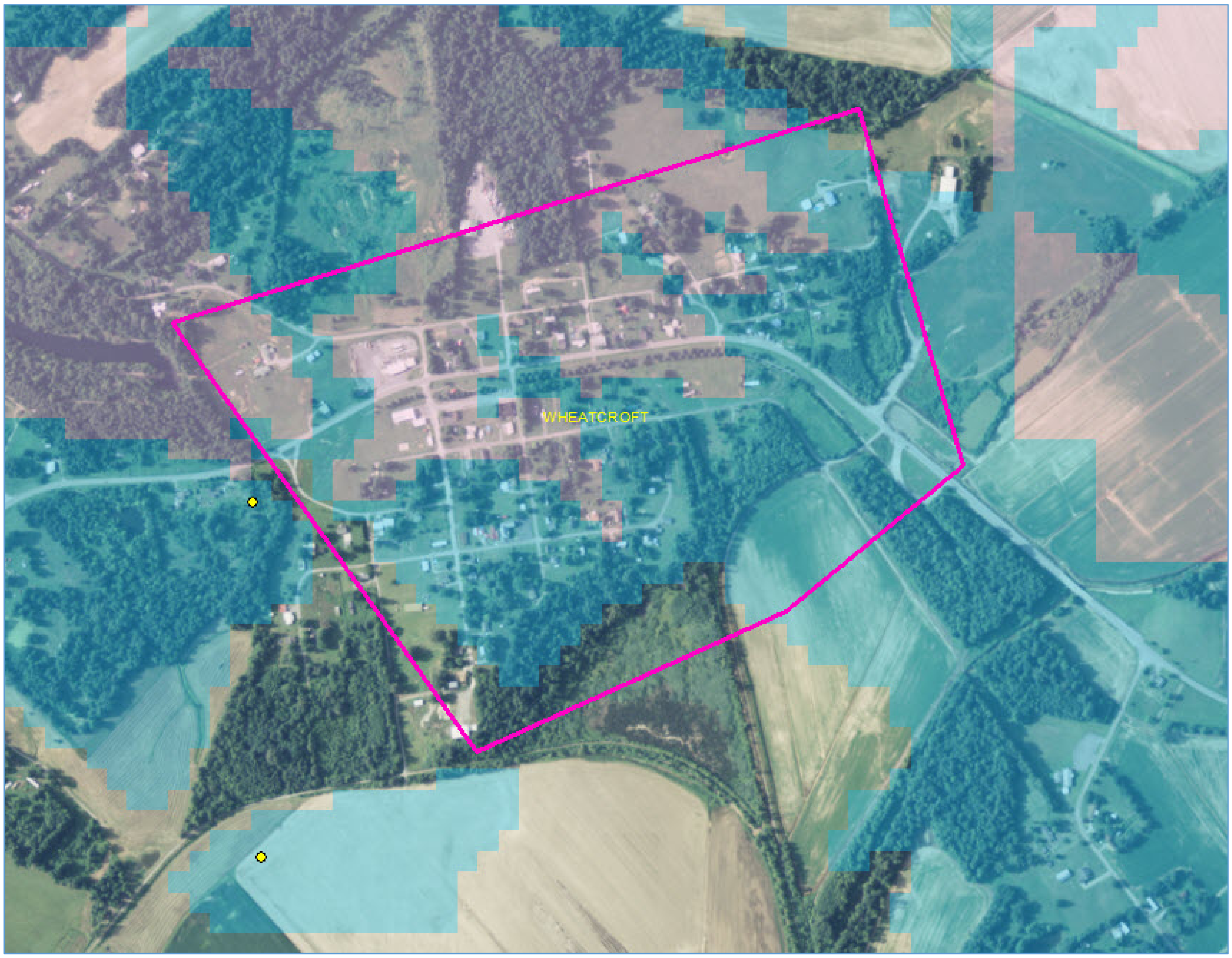


Figure 4-17b. Subsidence assessment data for part of Wheatcroft in western Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

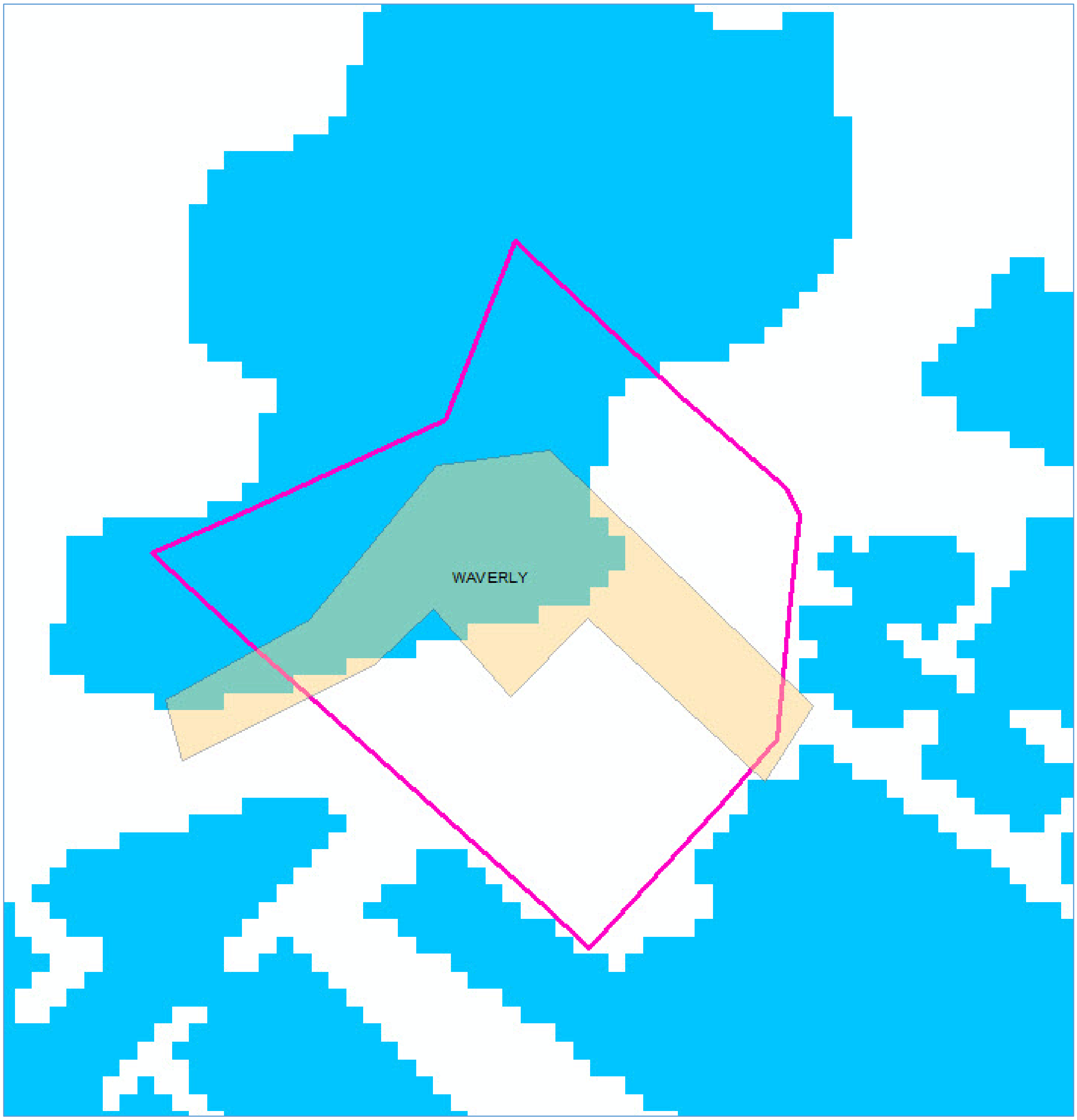


Figure 4-18a. Subsidence assessment data for part of Waverly in western Kentucky

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

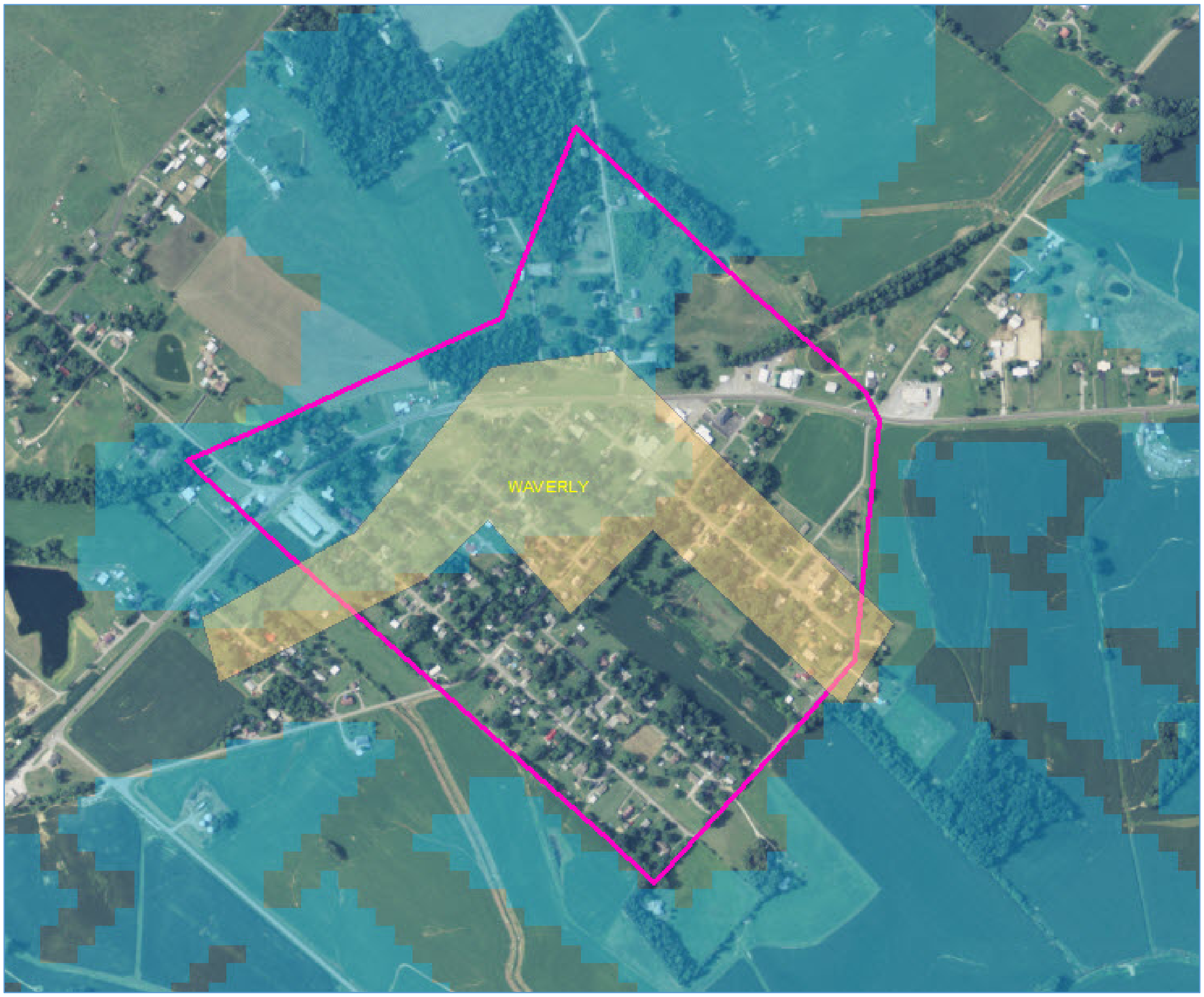


Figure 4-18b. Subsidence assessment data for part of Waverly in western Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

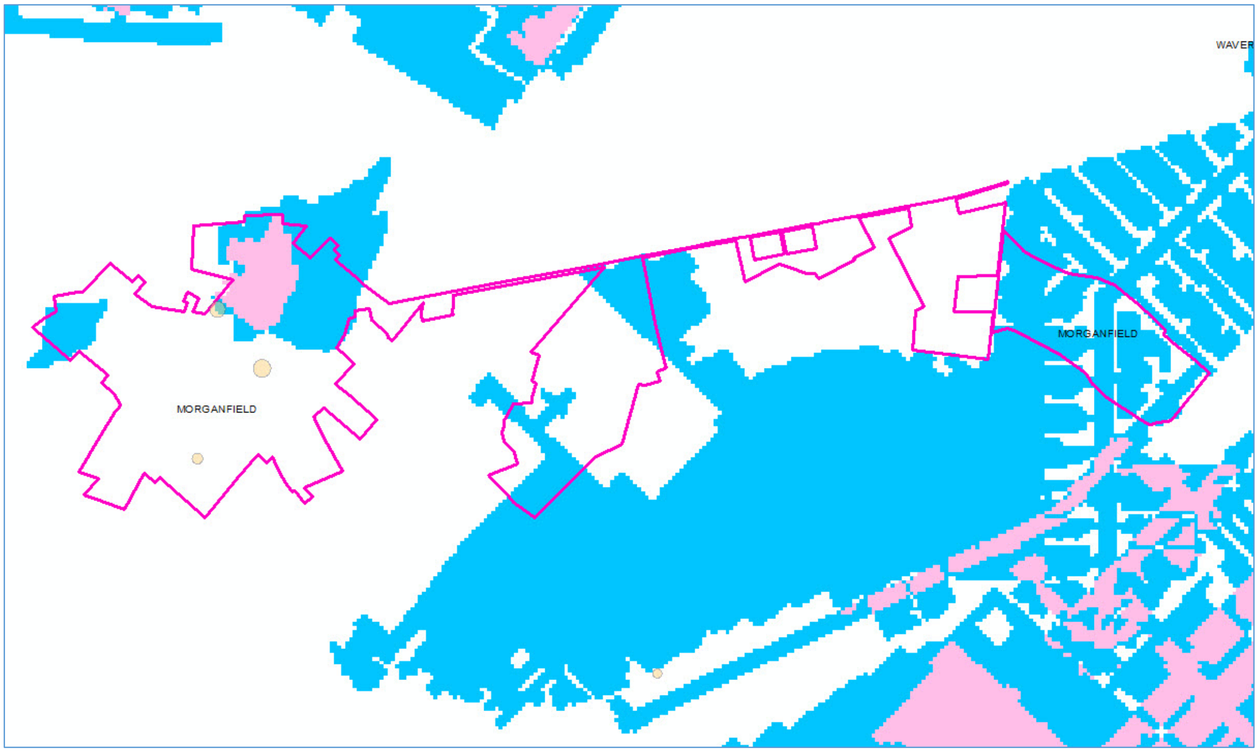
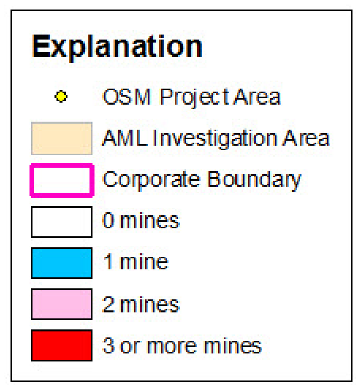


Figure 4-19a. Subsidence assessment data for part of Morganfield in western Kentucky



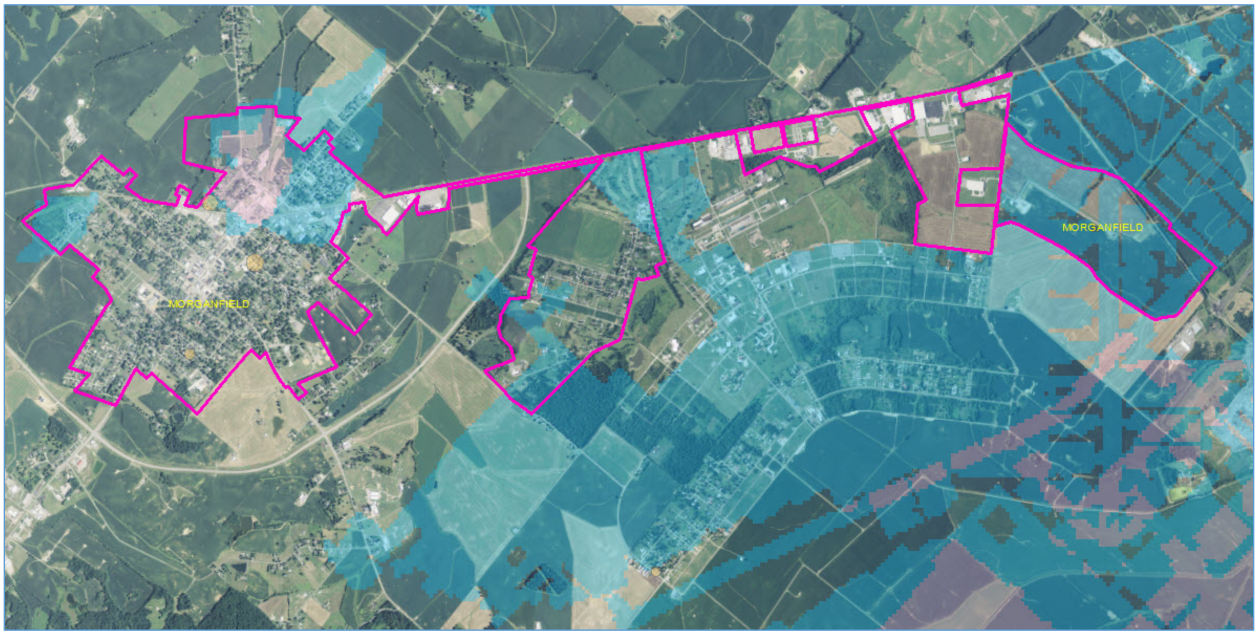


Figure 4-19b. Subsidence assessment data for part of Morganfield in western Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

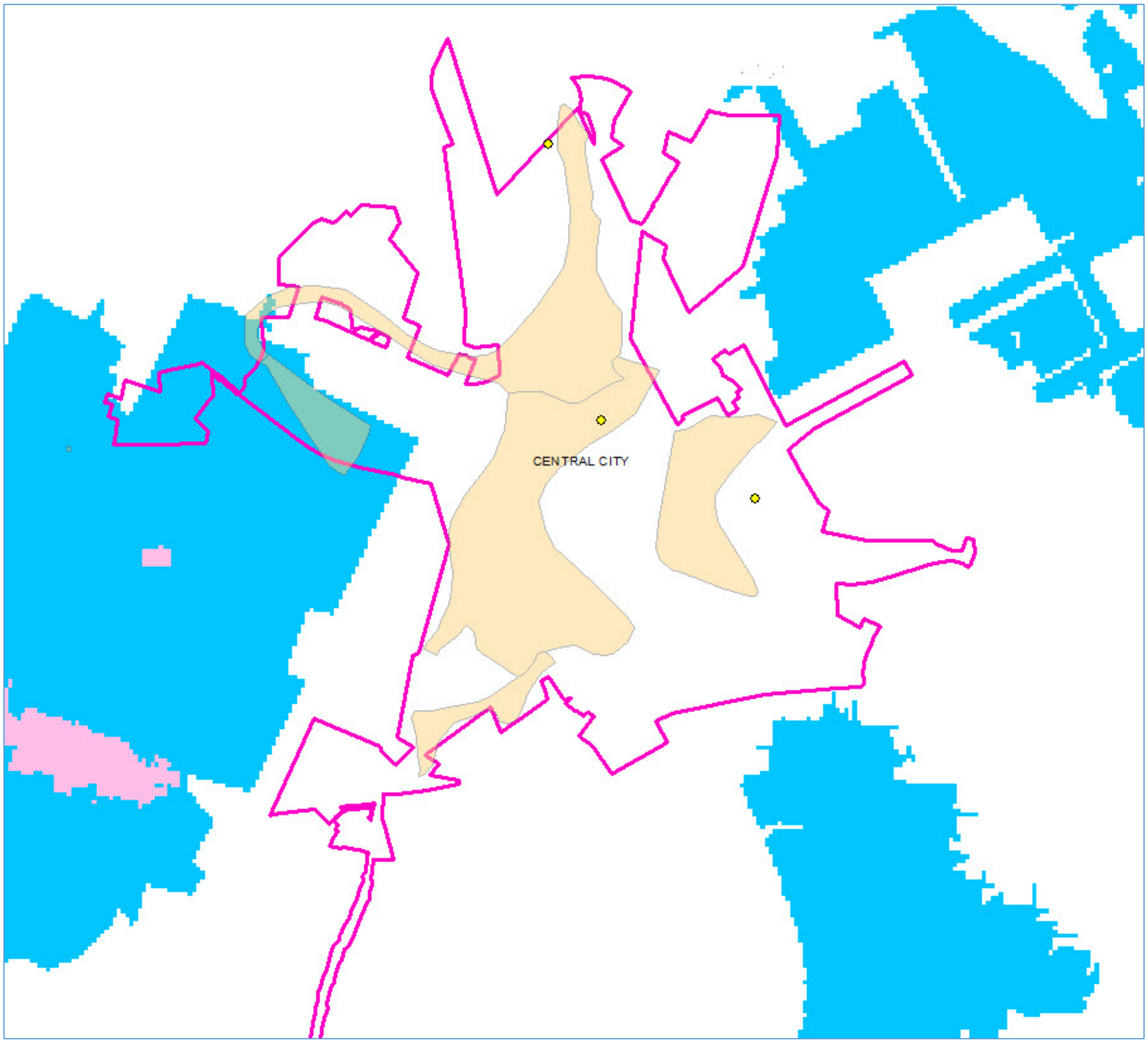
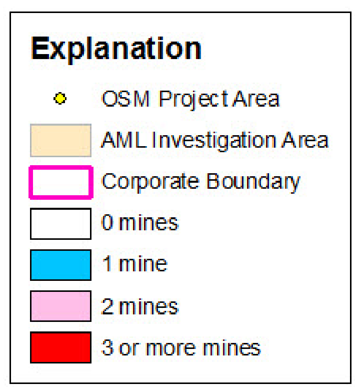


Figure 4-20a. Subsidence assessment data for part of Central City in western Kentucky



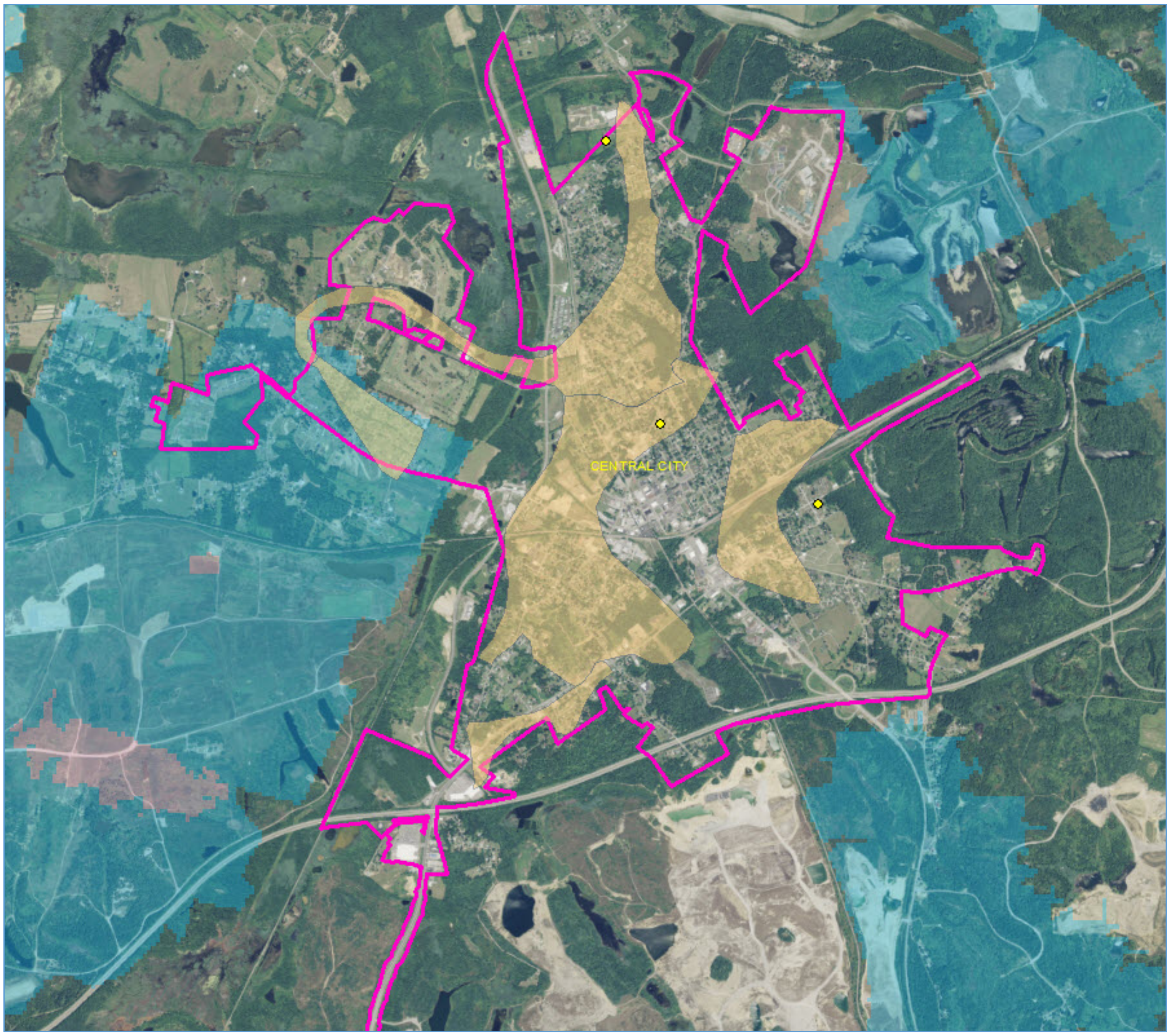
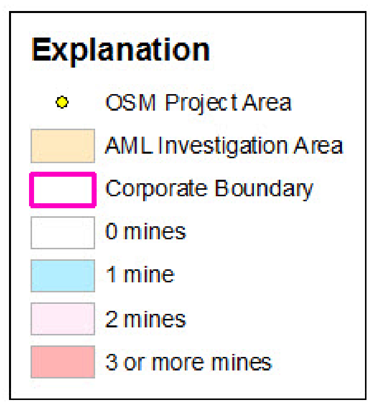


Figure 4-20b. Subsidence assessment data for part of Central City in western Kentucky, with aerial imagery



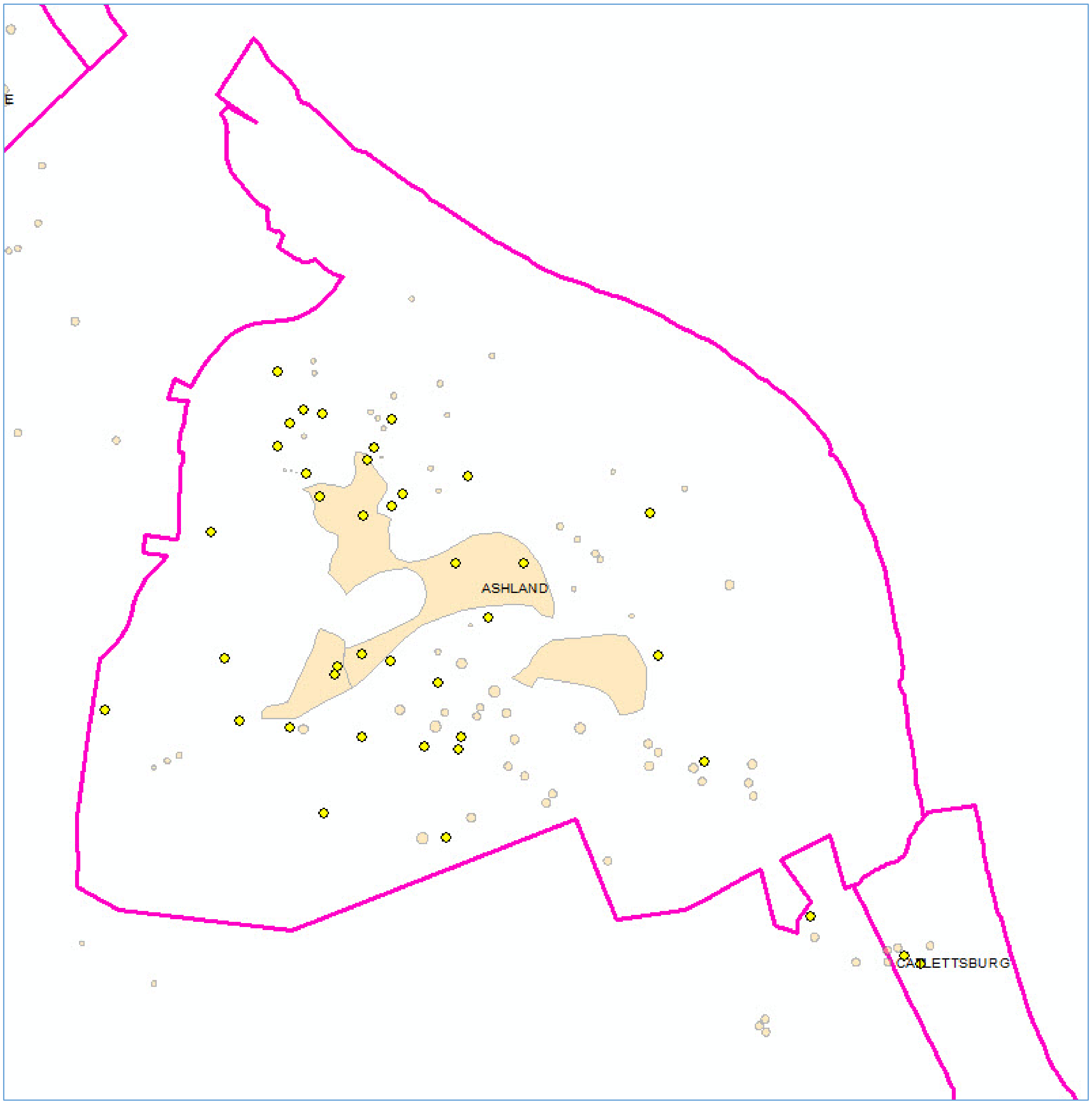
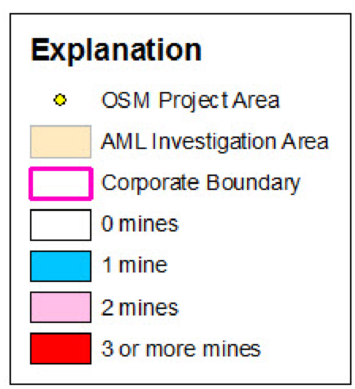


Figure 4-21a. Subsidence assessment data for part of Ashland in eastern Kentucky



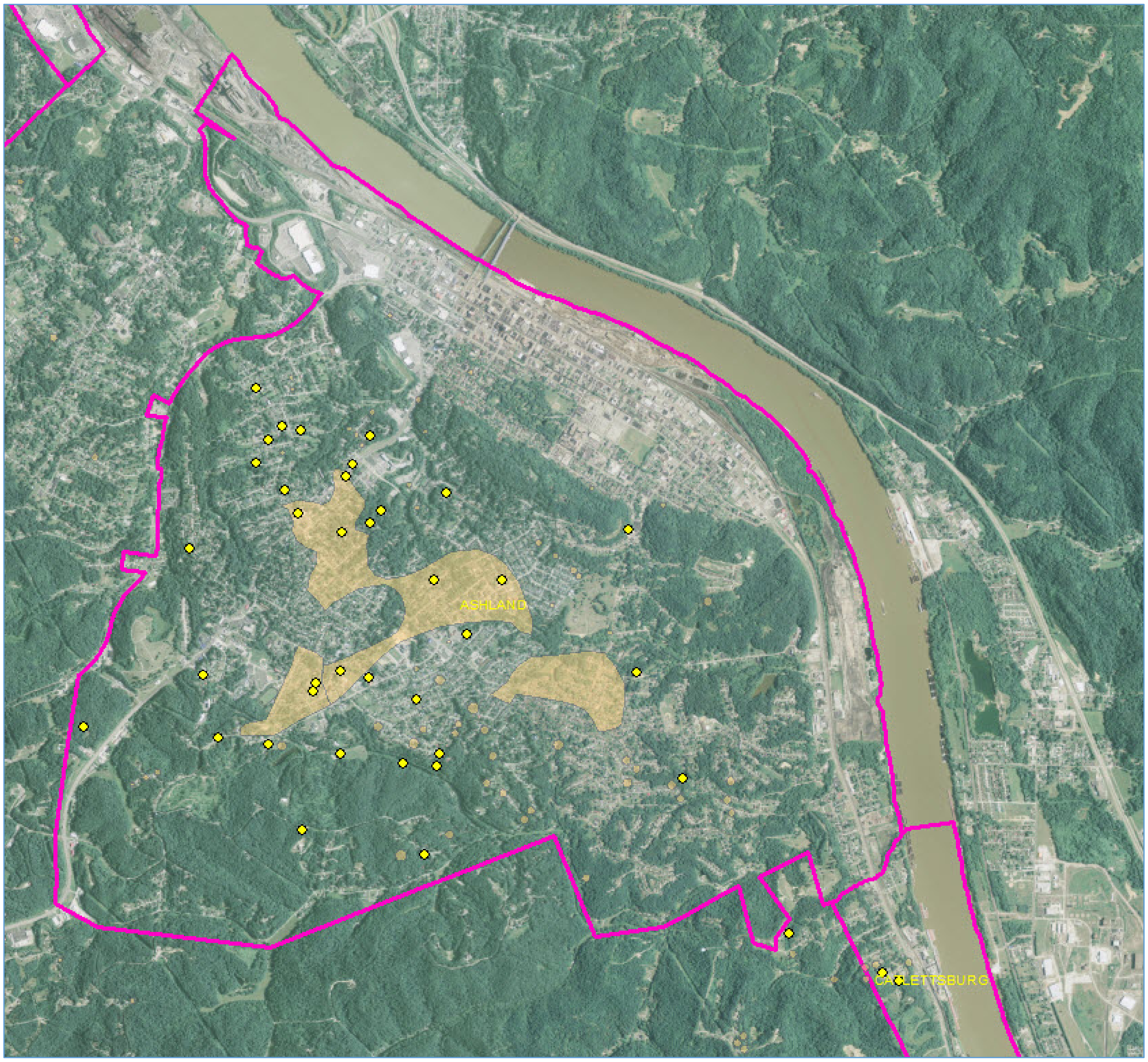


Figure 4-21b. Subsidence assessment data for part of Ashland in eastern Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines

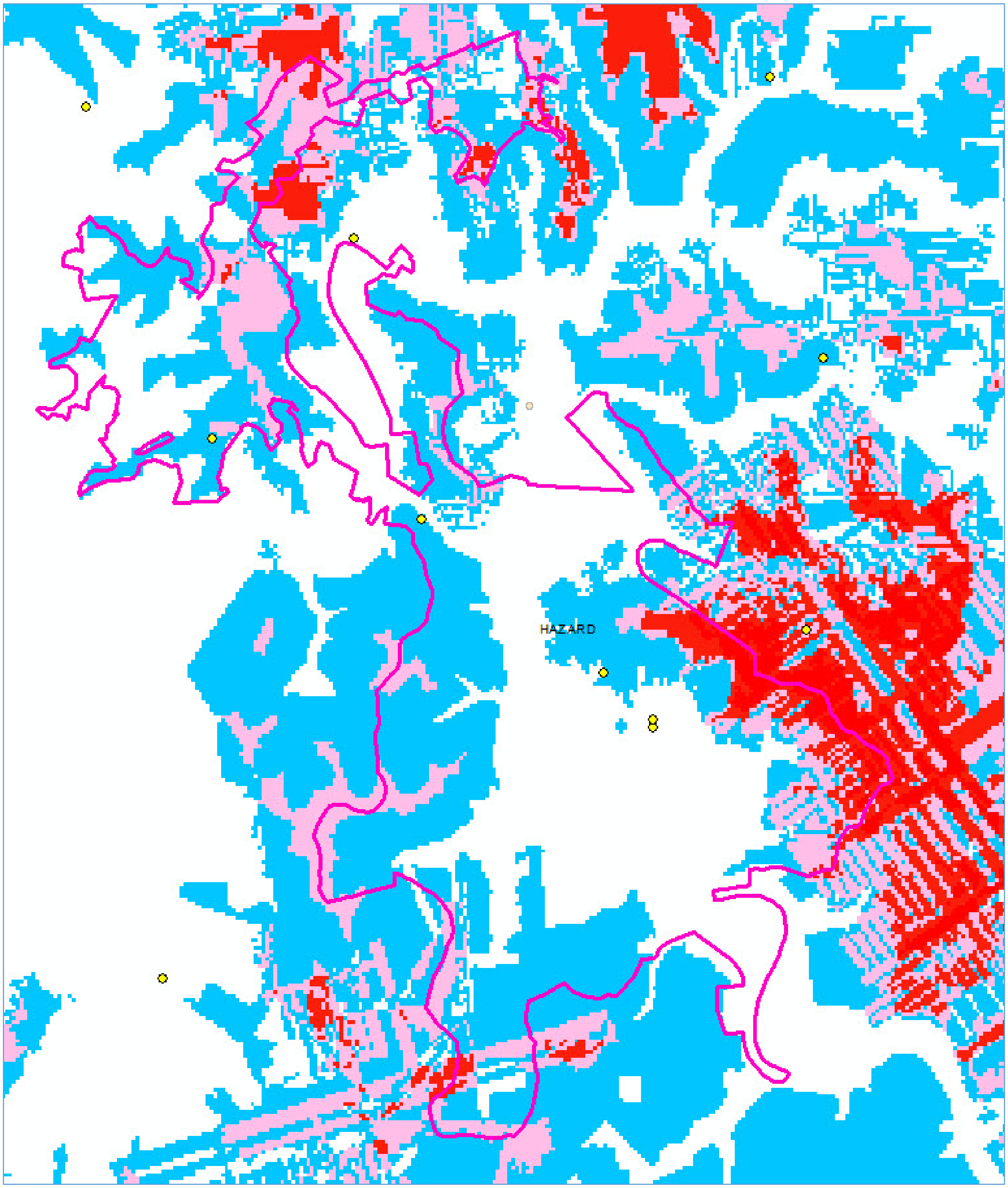


Figure 4-22a. Subsidence assessment data for part of Hazard in eastern Kentucky

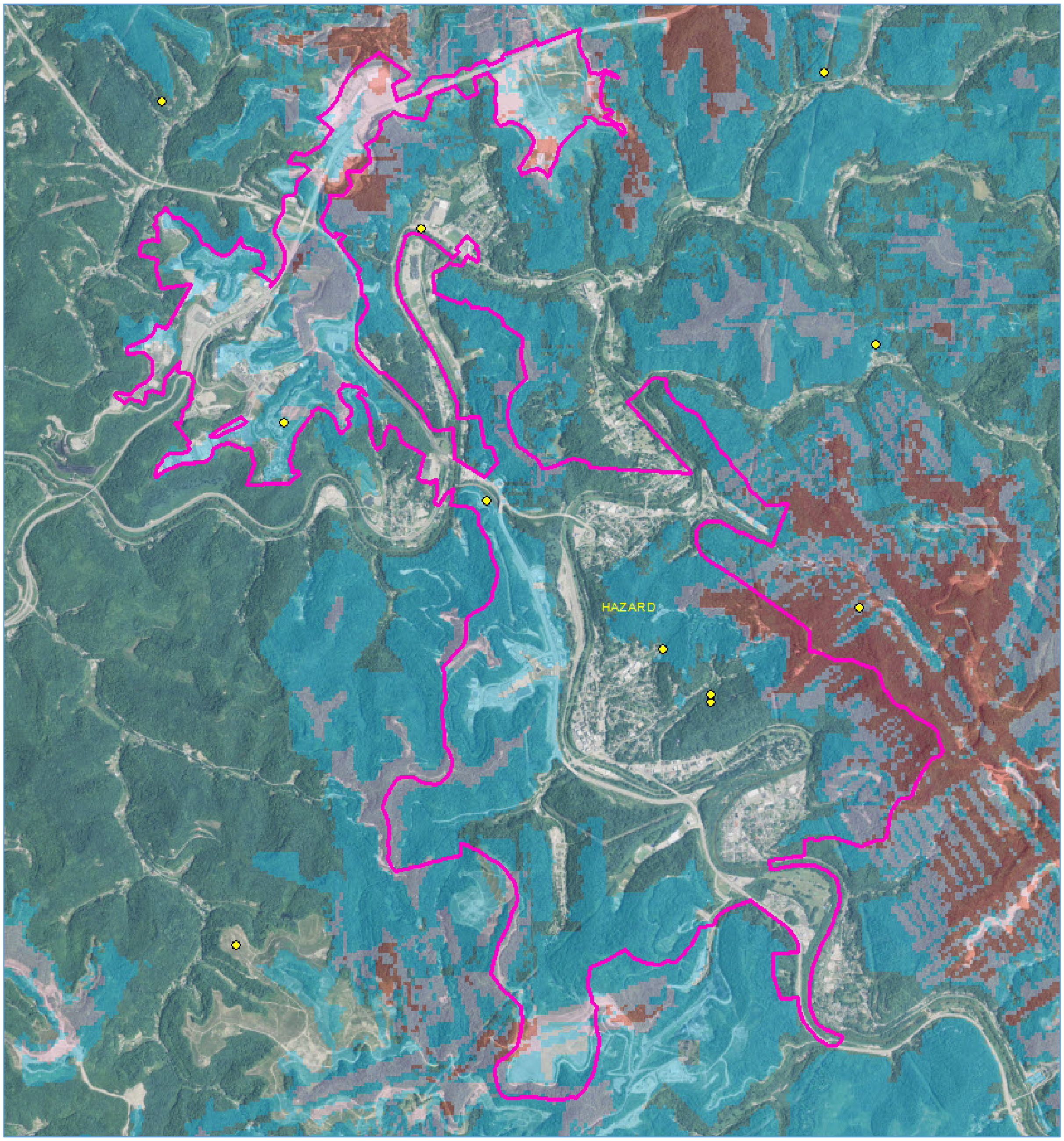
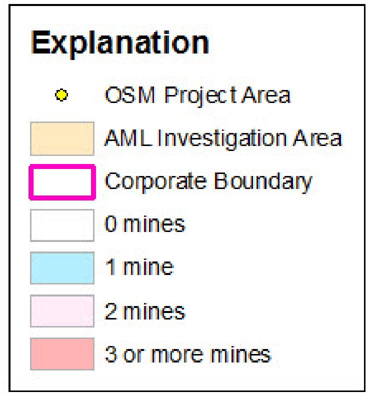

HAZARD

Figure 4-22b. Subsidence assessment data for part of Hazard in eastern Kentucky, with aerial imagery



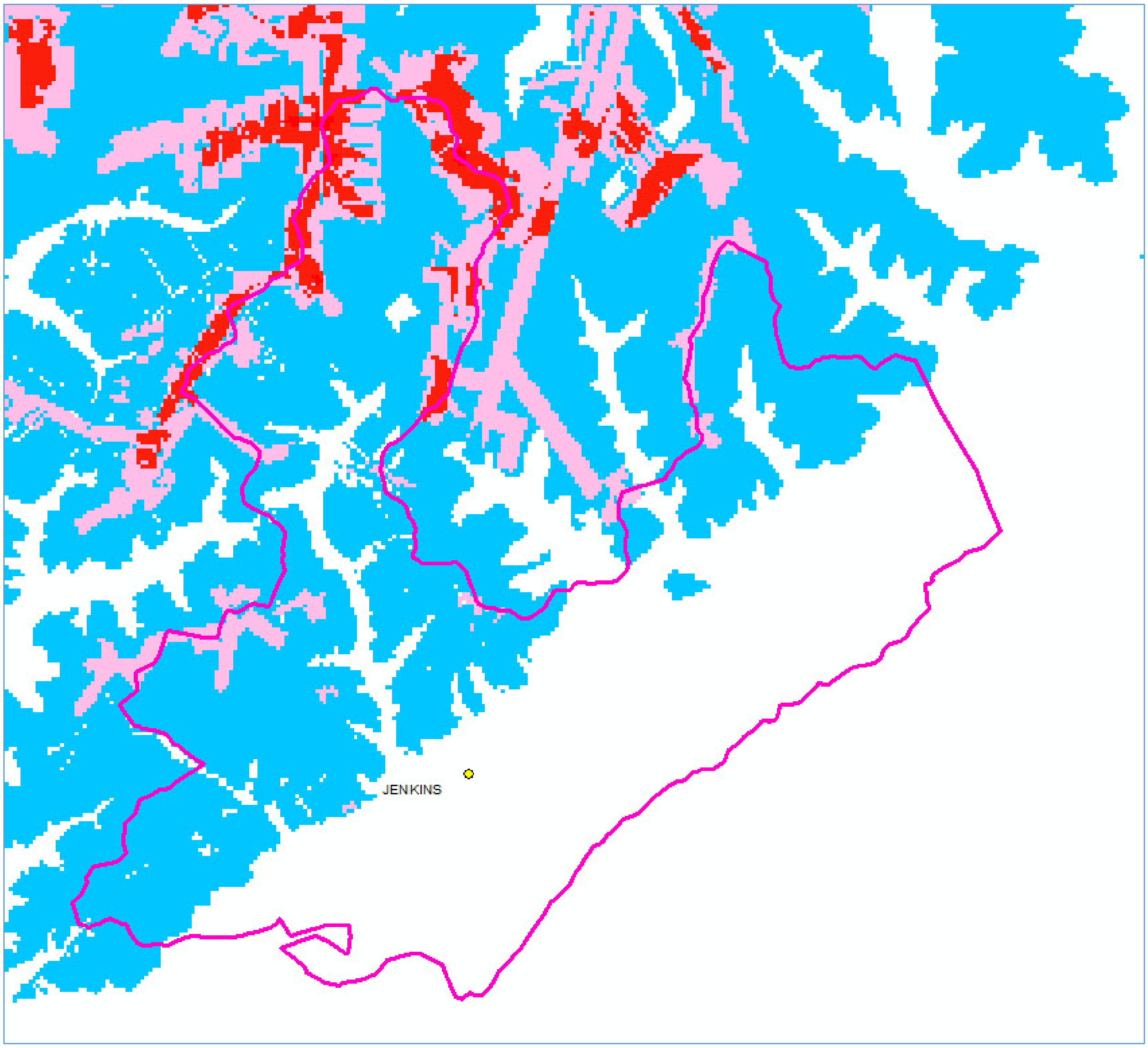
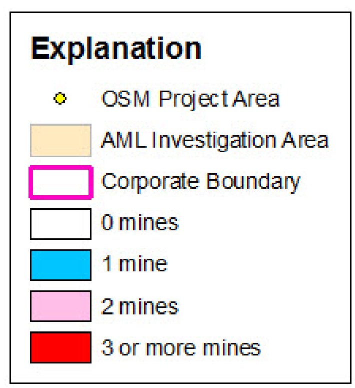


Figure 4-23a. Subsidence assessment data for part of Jenkins in eastern Kentucky



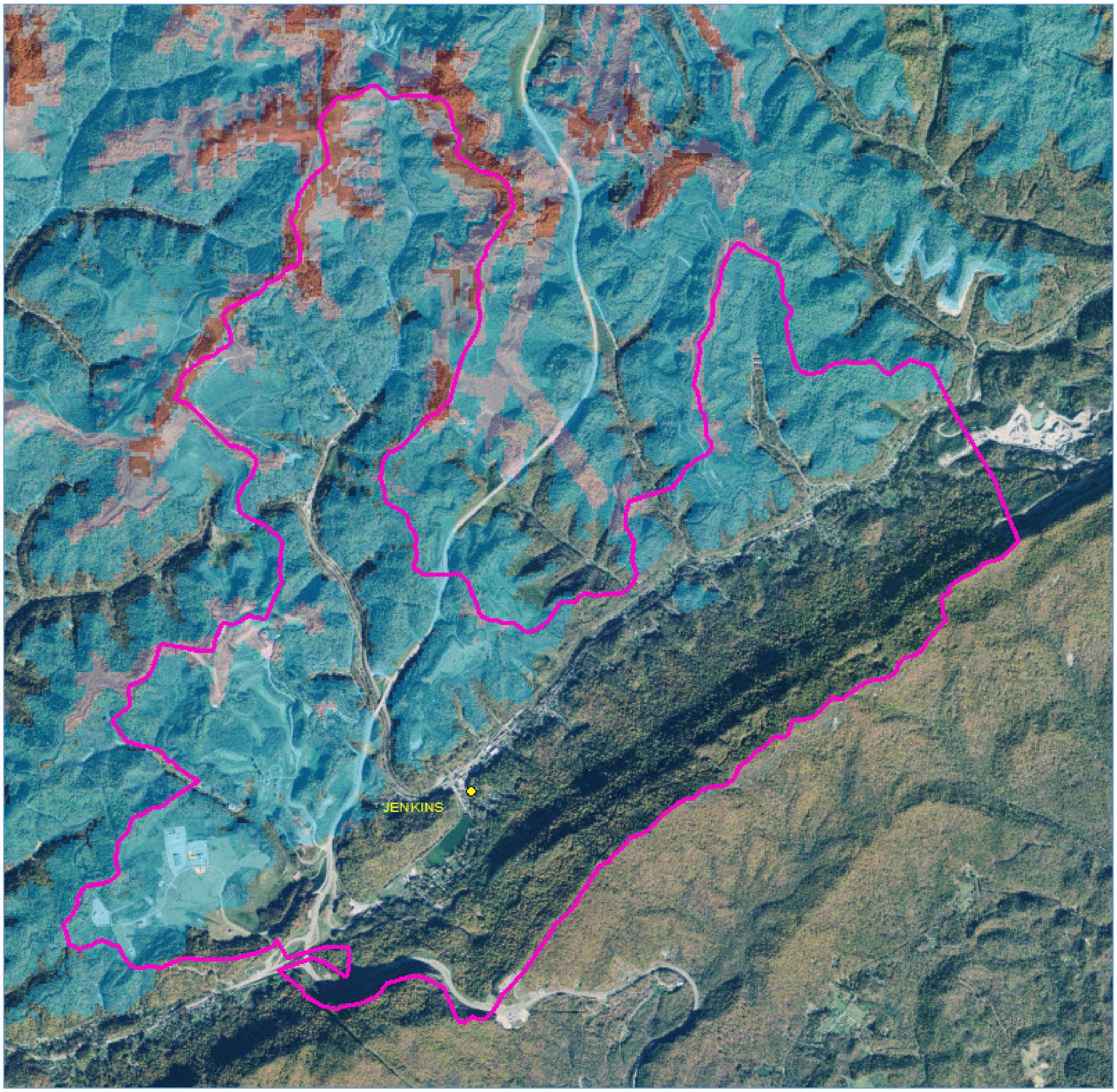


Figure 4-23b. Subsidence assessment data for part of Jenkins in eastern Kentucky, with aerial imagery

Explanation

- OSM Project Area
- AML Investigation Area
- Corporate Boundary
- 0 mines
- 1 mine
- 2 mines
- 3 or more mines