

FIGURE 14-4 Gas extraction-related disturbance identified between 2004 and 2010 in Washington County, Pennsylvania. Disturbance footprints are depicted in black. Simplified from Slonecker and others (2012, Figure 10).

facilitate a global approach to implementing new advanced remote sensing technologies for mapping and conservation of wetlands (Zomer and others, 2009).

ACCURACY ASSESSMENT

Land cover maps derived from remote sensing imagery are subjected to an accuracy assessment to enable the map to be confidently used for different applications. In general, an accuracy assessment of a land cover classification map compares the map to a more detailed, independently collected sample set named *verification* or *reference data*. The verification data can be based on field observations and visual interpretation of higher spatial resolution imagery. Congalton and Green (2008) provide extensive information on concepts, design, and implementation of accuracy assessment techniques.

Fifty samples for each land cover category is a good rule of thumb to obtain a statistically sound assessment (Congalton and Green, 2008). However, 50 samples per category are often impractical or economically unfeasible if collected solely in the field. More samples per land cover category can be achieved by including higher spatial resolution imagery that enables accurate identification of the land cover types. The location and number of verification sites for each land cover category should be included with the map.

VERIFICATION SITES (REFERENCE DATA)

In order to demonstrate the accuracy assessment methodology of Congalton and Green (2008), six land cover classes were created and mapped. The resulting polygons on Figure 14-5A were classified and labeled with a land cover category number (1 through 6). A limited number of verification sites were obtained for each of these land cover classes and plotted as black dots on the land cover map (Figure 14-5B). Visual inspection of the spatial distribution of the verification sites in Figure 14-5B shows that only the northern half of the map can be assessed for accuracy. The southern portion of the map lacks verification sites, perhaps because it is inaccessible to field crews or there is a lack of imagery with a higher spatial resolution than that used for the classification map. This accuracy assessment shortcoming should be documented in the map's metadata.

Thirty-one verification sites were used for the accuracy assessment. The number of verification sites per land cover category ranges from 4 to 6. The land cover category documented at each verification site was compared to the category mapped at the corresponding pixel(s) in the classification map. The site was correctly mapped if the verification site and map category agree. The site was incorrectly mapped (an error) if the verification site and map category do not agree. Table 14-8 lists the number of sites that agree with the map and the number of sites that do not agree for each category. A total of

FIGURE 14-5 Demonstration of the accuracy of the assessment methodology of Congalton and Green (2008).

| Class | Land cover category |
|-------|---------------------|
| 1 | Water |
| 2 | Wetlands |
| 3 | Industry |
| 4 | Trees |
| 5 | Grass |
| 6 | Suburbs |

21 sites were correctly mapped while 10 sites were incorrectly mapped. The verification site IDs are listed Table 14-8.

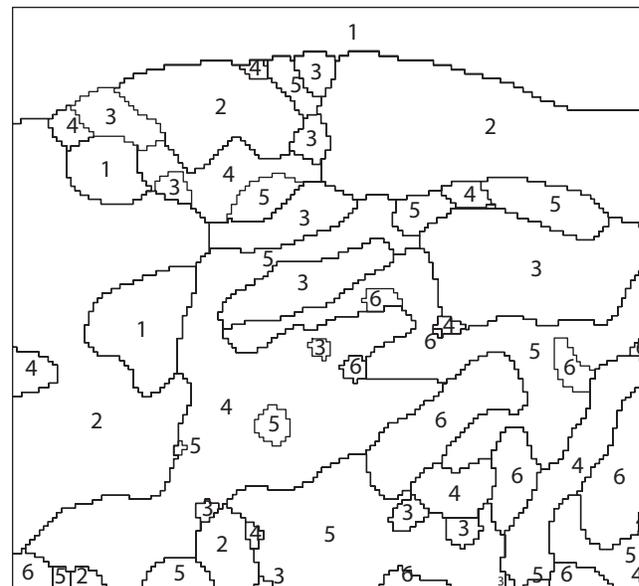
Table 14-9 provides information on which verification sites agree (C) and disagree (B) with the land cover map. It shows the correct category (A) for those verification sites that were incorrectly mapped. For example, verification site ID 6 was categorized as wetlands, but it was mapped as water. Suburbs, grass, and trees have many incorrect (B) and misclassified (A) entries in Table 14-9, indicating spectral similarities that results in classification errors on the map.

ERROR MATRIX

An accuracy assessment *error matrix* quantifies the correct and incorrect categories on a land cover map in a standardized manner (Congalton and Green, 2008). Table 14-10 is the error matrix for the land cover map and verification sites shown in Figure 14-5. The error matrix compares information from verification sites to information on the map for all of the sample sites. The matrix is a square array of numbers set out in rows and columns that express the labels of samples assigned to a particular category in the verification data relative to the labels of samples assigned to a particular category on the map.

Within the error matrix, Column Total is the total number of samples in each column or category, is assumed to be correct, and is termed the *reference data*. Row Total displays the total number of samples in each category on the map and is termed the *classified data*. If the classified map was 100% accurate, the integers found in the Column Total and

A. Land cover map with six classes.



B. Land cover map with verification sites added (black dots) (Table 14-8).

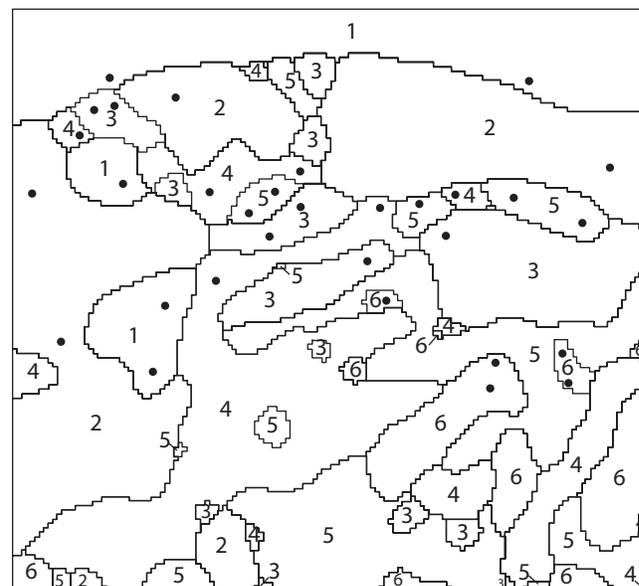


TABLE 14-8 Characteristics of verification sites.

| Class | Land Cover Category | Number of Verification Sites | Map and Verification Sites Agree (Correct) | Map and Verification Sites Do Not Agree (Error) | Verification Site ID |
|-------|---------------------|------------------------------|--|---|----------------------|
| 1 | Water | 5 | 5 | 0 | 1-5 |
| 2 | Wetlands | 4 | 3 | 1 | 6-9 |
| 3 | Industry | 6 | 4 | 2 | 10-15 |
| 4 | Trees | 6 | 3 | 3 | 16-21 |
| 5 | Grass | 5 | 2 | 3 | 22-27 |
| 6 | Suburbs | 5 | 4 | 1 | 28-31 |
| Total | | 31 | 21 | 10 | |

the Row Total cells would be equal for each category. The numbers in the Column Total and Row Total cells always sum to the same value—in this example to 31—that is, the total number of verification sites in our accuracy assessment. Error matrices are very effective representations of map

accuracy, because the individual accuracies of each map category are plainly described. The overall accuracy is simply the sum of the major diagonal (i.e., the correctly classified pixels or samples) divided by the total number of pixels or samples in the error matrix.

TABLE 14-9 Summation of correct and incorrect areas (pixels) on land cover classification map.

| Verification Site ID | Water | Wetlands | Industry | Trees | Grass | Suburbs |
|----------------------|-------|----------|----------|-------|-------|---------|
| 1 | C | | | | | |
| 2 | C | | | | | |
| 3 | C | | | | | |
| 4 | C | | | | | |
| 5 | C | | | | | |
| 6 | B | A | | | | |
| 7 | | C | | | | |
| 8 | | C | | | | |
| 9 | | C | | | | |
| 10 | | | A | | B | |
| 11 | | | C | | | |
| 12 | | | C | | | |
| 13 | | | A | | | B |
| 14 | | | C | | | |
| 15 | | | C | | | |
| 16 | | | | C | | |
| 17 | | | | A | | B |
| 18 | | | | A | | B |
| 19 | | | | C | | |
| 20 | | | | A | | B |
| 21 | | | | C | | |
| 22 | | | | | C | |
| 23 | | | | | A | B |
| 24 | | | | | A | B |
| 25 | | B | | | A | |
| 26 | | | | | C | |
| 27 | | | | | | C |
| 28 | | | | | | C |
| 29 | | | | | | C |
| 30 | | | | B | | A |
| 31 | | | | | | C |
| Total | 6 | 4 | 4 | 4 | 3 | 10 |

Grand Total = 31

A = Right answer for incorrectly (B) classified pixel(s) based on verification data.

B = Incorrect: Pixel(s) mapped as this category *does not agree* with verification data.

C = Correct: Both classified map and verification data *agree* on category.

Total = number of correct (C) and incorrect (B) in each category. (A) is not included.

Grand Total = number of correct (C) and incorrect (B) areas (pixels) on classified map for all categories. (A) is not included.

TABLE 14-10 Accuracy assessment error matrix.

| | | Reference Data | | | | | | Row Total |
|-----------------|---|---|----------|----------|-------|-------|---------|-----------|
| | | What is the Category According to the Verification Sites? | | | | | | |
| Classified Data | What is the Category According to the Classification Map? | Water | Wetlands | Industry | Trees | Grass | Suburbs | |
| | | Water | 5 | | | | | |
| | Wetlands | 1 | 3 | | | | | 4 |
| | Industry | | | 4 | | 1 | 1 | 6 |
| | Trees | | | | 3 | | 3 | 6 |
| | Grass | | 1 | | | 2 | 2 | 5 |
| | Suburbs | | | | 1 | | 4 | 5 |
| | Column Total | 6 | 4 | 4 | 4 | 3 | 10 | 31 |

Black box (correct) = classification map and verification site have the same category (C in Table 14-9).

Gray box (error) = classification map and verification site are different (B in Table 14-9).

Total correct = 5 + 3 + 4 + 3 + 2 + 4 = 21.

Overall accuracy = 21 / 31 = 68%.

The overall accuracy for the land cover map (Figure 14-5A) is 68%. An overall accuracy of 85% is acceptable in many applications. The error matrix indicates that trees and grass are the least accurately mapped categories. In addition, many categories are misclassified as suburbs. Standardized accuracy measures of *individual* land cover categories, such as trees, grass, and suburbs, can be extracted from the error matrix (Congalton and Green, 2008). Improving the training sites for supervised classification, reducing the number of land cover categories (generalization), changing the parameters for unsupervised classification, manual editing of the map's attribute table, and employing a sensor with higher spectral and spatial resolution are techniques used to increase the map accuracy of individual classes.

DASYMETRIC MAPS

Human population distributions are commonly displayed using census data. However, these data are aggregates of geographic units (census tracts or block groups) whose boundaries do not always reflect the natural distribution of human populations. A *dasymetric* mapping technique is one potential solution for mapping population density relative to residential land use. Dasymetric mapping depicts quantitative areal data using boundaries that divide the area into zones of relative homogeneity with the purpose of better portraying the population distribution (USGS, 2017a).

Census tracts with population density are shown in Figure 14-6A. For this example, the population density is provided

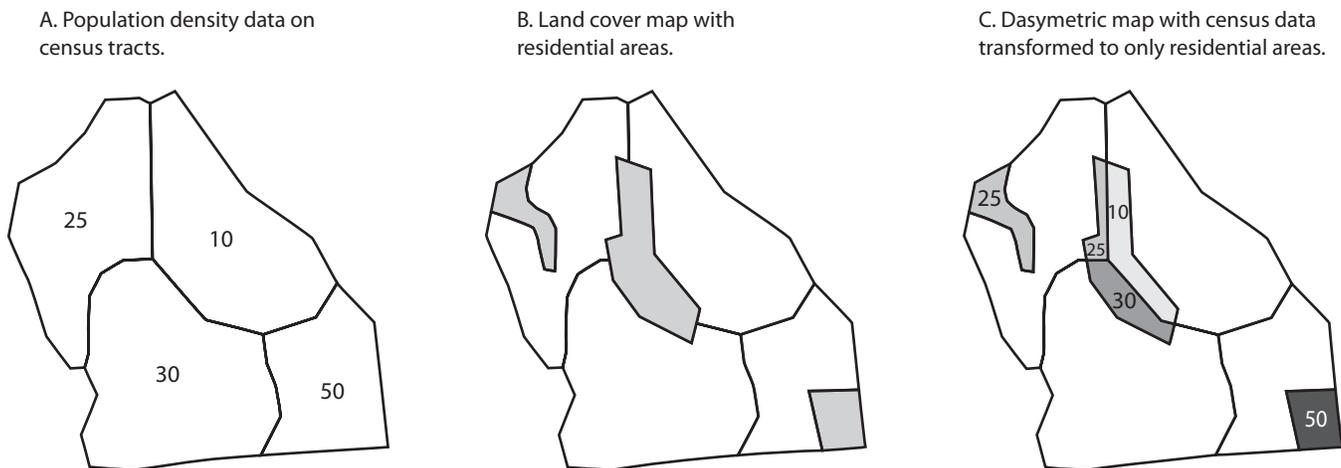


FIGURE 14-6 Transformation of population density data on census tracts to a dasymetric map incorporating land cover maps of residential areas.