How to Estimate Future Land Cover in a Watershed

Estimating future land cover in a watershed is important in the context of a watershed plan because it provides a snapshot of future conditions, which encourages local planners to rethink where and how development will occur in order to protect natural resources, reduce degradation of streams, provide clean drinking water for residents, and reduce stormwater management and flood control costs.

The method described below is a GIS analysis that estimates future land cover in a watershed, and can also be used to evaluate the effect of different watershed protection scenarios on future land cover. The results are useful for predicting future health of streams, setting numeric goals for forest cover, and developing watershed protection recommendations.

GIS data and other information needed for this analysis include:

- Property boundaries and associated parcel data
- Current land cover: impervious, forest, turf, cropland, etc
- Zoning
- Protected land (will vary with local regulations)
- Land cover coefficients
- Recent aerial photos are also helpful
- Knowledge of local environmental and development regulations

Assumptions:

- Full buildout of the watershed will occur based on allowable zoning (e.g., no rezoning)
- Current land cover on developed land will remain the same in the future buildout scenario unless specific land cover changes are identified in watershed protection scenario (e.g., reforestation, removal of impervious cover)
- Protected land will remain the same in future buildout scenario
- Buildable land will be converted to impervious cover, forest, or turf, as dictated by land cover coefficients

Steps:

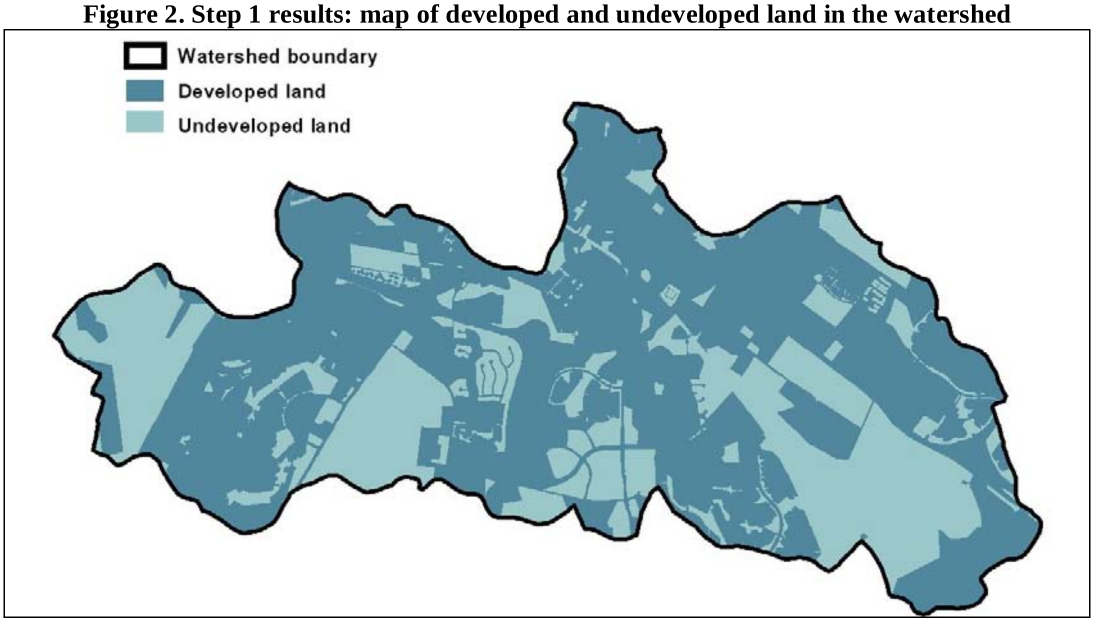
1. Identify developed and undeveloped parcels
2. Calculate the area of each zoning category for undeveloped land
3. Identify and subtract protected land from undeveloped land for each zoning category
4. Multiply the remaining buildable land in each zoning category by the corresponding land cover coefficients
5. Calculate the area of each land cover type for developed land and protected land
6. Sum future land cover on buildable, developed, and protected land

Step 1. Identify developed and undeveloped parcels
Property boundaries and associated parcel data may be used to identify which parcels are developed and undeveloped. If no information is available about which parcels are developed or undeveloped, use the GIS to select out the parcels that intersect with building and/or road layers

(Figure 1). Existing highways should also be included in the developed land layer. The result of this step is a new GIS layer for developed land and for undeveloped land (Figure 2).

Figure 1. Use GIS to select out developed parcels (parcels with buildings on them)

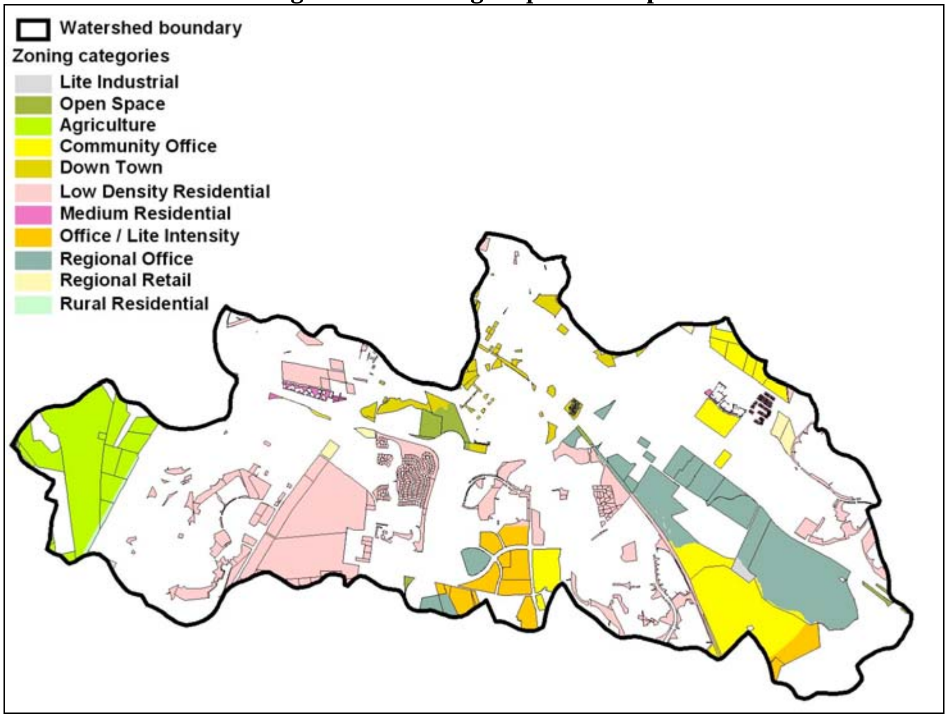
Figure 2. Step 1 results: map of developed and undeveloped land in the watershed



Step 2. Calculate the area of each zoning category for undeveloped land

This step requires intersecting the zoning layer with the undeveloped land layer. The result is a new GIS layer of undeveloped land classified according to zoning category (Figure 3). This layer should also have an associated data table that includes the calculated area of each zoning category for undeveloped land in the watershed.

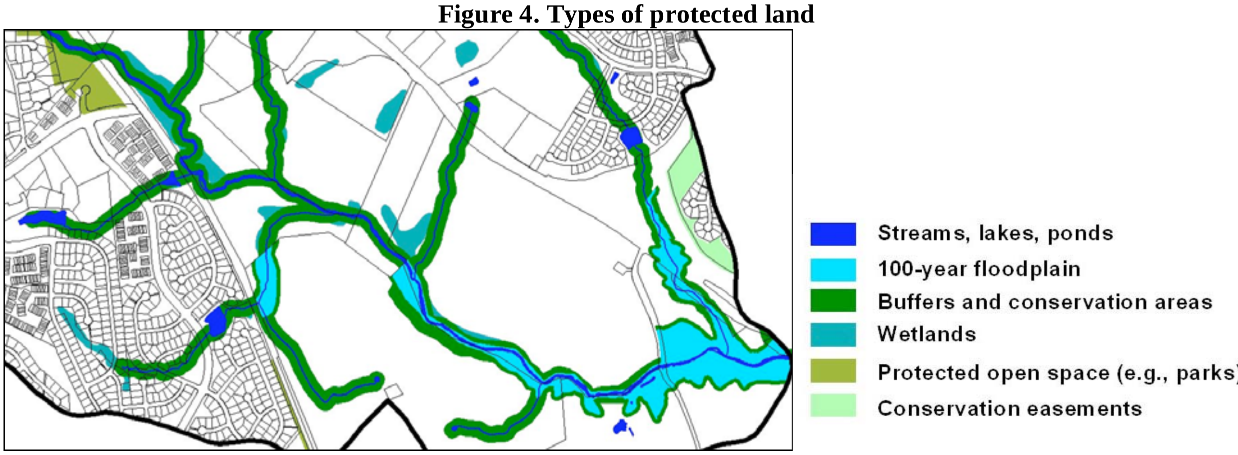
Figure 3. Resulting map from Step 2



Step 3. Identify and subtract protected land from undeveloped land for each zoning category

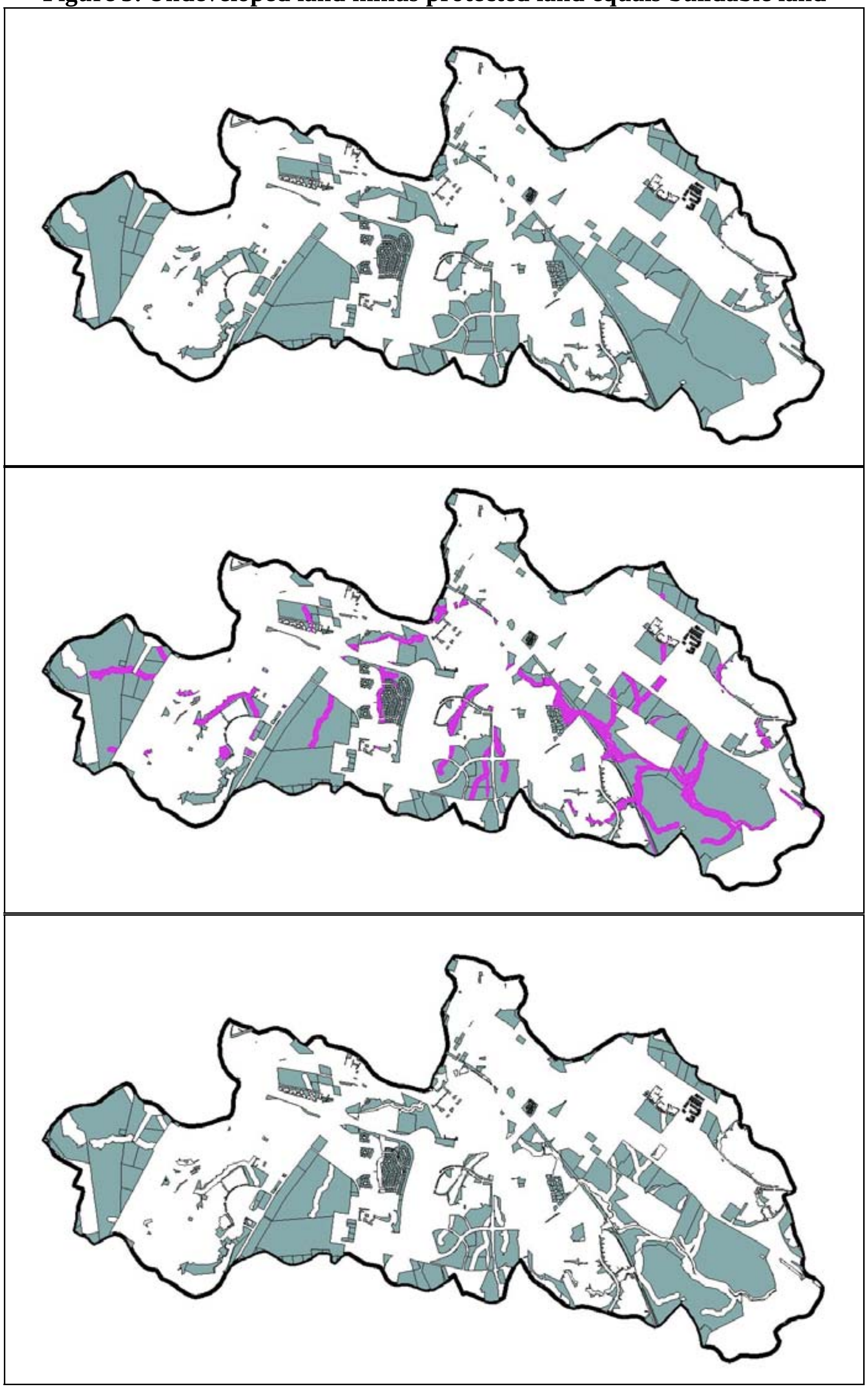
This step subtracts protected land from undeveloped land to identify land that is considered "buildable" according to local zoning and regulations. Protected land includes parcels that are permanently protected from development such as parkland, conservation easements and conservation zones, as well as other types of land that are protected by local regulations, such as stream buffers, floodplains, wetlands, steep slopes, karst features, erodible soils, and hydric soils (Figure 4). Only land that falls into one of the above categories should be subtracted from undeveloped land, and will vary according to local regulations.

Figure 4. Types of protected land



GIS layers for each type of protected land are required for this step. This might involve, for example, creating a 100-foot buffer of the stream layer or using a topography layer to identify slopes greater than 25%. Protected lands should be merged into one layer and subtracted out from the undeveloped land. The end result is a new GIS layer of buildable land classified by zoning category (Figure 5), and a data table with corresponding areas.

Figure 5. Undeveloped land minus protected land equals buildable land



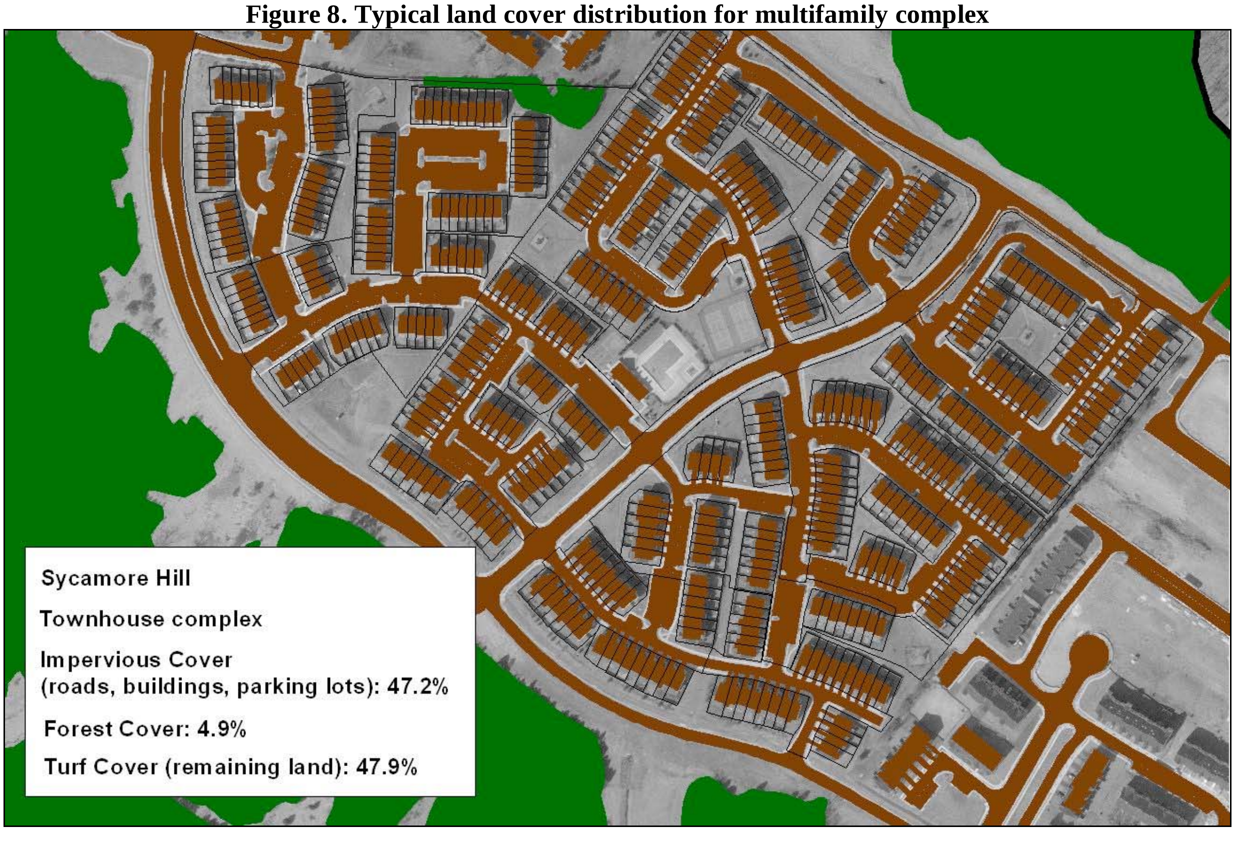
Step 4. Multiply the remaining buildable land in each zoning category by the corresponding land cover coefficients

Land cover coefficients represent the fraction of a land use parcel that is a particular land cover type, and are used to predict future land cover on buildable land. Land cover coefficients vary by land use type and intensity. Figures 6-8 illustrate how the proportion of impervious, forest and turf cover varies for three different types of developments.

Figure 6. Typical land cover distribution for residential subdivision

Figure 7. Typical land cover distribution for commercial development

Figure 8. Typical land cover distribution for multifamily complex



Impervious cover coefficients are available from Cappiella and Brown (2001). These numbers were developed by sampling more than 200 land use polygons within four Chesapeake Bay communities to calculate an average impervious cover for 12 land use categories. The resulting coefficients are provided in Table 1.

Cappiella and Brown (2001) have shown that the amount of impervious cover on a development parcel is generally very similar for a particular zoning category no matter where it is located. However, the amount of forest and turf cover may vary greatly and is dependent on the following factors:

- Land use type and intensity
- Pre-existing land cover (e.g., agriculture versus forest)
- Local forest conservation regulations
- Local clearing and grading practices
- Local reforestation and landscaping requirements
- Age of development

Table 1. Impervious Cover Coefficients from Cappiella and Brown (2001)

Land Use Category	Mean Impervious Cover	Notes
Agriculture	**1.9** ± 0.3	Crop and pasture land
Open Urban Land	**8.6** ± 1.64	High variability, range = 2.4 to 21.5. Includes parks, golf courses, cemeteries
2 Acre Lot Residential	**10.6** ± 0.65	Counties variable, range = 8.7 to 12.7
1 Acre Lot Residential	**14.3** ± 0.53	
½ Acre Lot Residential	**21.2** ± 0.78	
1/4 Acre Lot Residential	**27.8** ± 0.60	
1/8 Acre Lot Residential	**32.6** ± 1.6	Includes duplexes
Townhome Residential	**40.9** ± 1.39	
Multifamily Residential	**44.4** ± 2.0	Apartments/condos
Institutional	**34.4** ± 3.45	High variability, range = 8.4 to 82.0. Includes churches, schools, hospitals, government offices, police and fire stations
Light Industrial	**53.4** ± 2.8	No heavy industry
Commercial	**72.2** ± 2.0	No regional malls, includes strip malls and central business districts

Forest and turf cover coefficients are an important data gap. Until nationally applicable coefficients are developed that account for the variability in forest and turf cover described above above, preliminary estimates or best professional judgment should be used. Some examples are provided below for making preliminary estimates of forest cover coefficients.

- If the typical practice in your community is to clear the entire development site, and no local forest conservation regulations exist, assume the forest cover coefficient for all land use types is 0. This would represent future forest cover under the "worst-case" scenario.
- If local forest conservation regulations do exist, use the required conservation thresholds as preliminary forest cover coefficients (see Maryland example below).
- Use data from American Forests' Urban Ecosystems Analyses. The Urban Ecosystems Analyses quantify tree cover in urban areas and quantify the benefits and services provided by these trees. This analysis has been done for more than 30 cities and metropolitan regions nationwide. The resulting reports often contain data on the average forest cover for different land use types, which may be used as preliminary forest cover coefficients. Check to see if a report is available for your city at: http://www.americanforests.org/resources/urbanforests/analysis.php
- Use data from the USDA Forest Service's Urban Forest Effects Model. The UFORE model also quantifies tree cover in urban areas and evaluates planting potential. Resulting data includes tree and grass cover percentages by land use type, which can be used as preliminary land cover coefficients. UFORE studies have been completed for nine cities in the U.S and Canada. Check to see if data is available for your city at: www.ufore.org
- Develop locally applicable coefficients using methods outlined in Cappiella and Brown (2001).

In Maryland, the Forest Conservation Act (FCA) requires conservation of forests during development. According to the FCA, sites must have a specific percentage of forested land. Sites that have a lot of existing forest cover must follow specified conservation thresholds for various land use types when clearing forests. If sites have a low percentage of existing forest cover (typical of agricultural sites), then afforestation thresholds apply (e.g., tree planting is required). Theoretically if the FCA is effective, developed land should have at least the amount of forest specified by the FCA for that land use type.

The FCA does not apply to low-density residential development, however local forest conservation ordinances may set thresholds for all types of development. Frederick County, Maryland has done so, and these thresholds, shown in Table 2, may be used as preliminary forest cover coefficients. Because the FCA sets thresholds for both conservation and afforestation, two sets of forest cover coefficients are shown in Table 2: one set applies to land with a lot of existing forest cover, while the other set applies to sites with a low percentage of existing forest cover (e.g., agricultural land). These numbers may need to be adjusted downward to account for protected lands (such as stream buffers) that may be counted towards forest conservation requirements.

Table 2. Preliminary forest cover coefficients for Frederick County, Maryland

based on Forest Conservation Ordinance		
Zoning Category	**Current Land Cover (predominant)**	
	Forest	**Agriculture**
Agriculture, Resource Conservation	.50	.20
Low Density Residential (R-1)	.25	.20
Medium and High Density Residential (R-3, R-5, R-8, R-12, R-16, Mobile Homes), Institutional	.20	.15
Mixed Use, Planned Unit Development, Commercial, Industrial	.15	.15

Once land cover coefficients are obtained, the buildable area for each zoning category should be multiplied by the corresponding land cover coefficients. This results in an estimate of future land cover for buildable land in the watershed. Table 3 illustrates this calculation for future forest cover.

Table 3. Estimating Future Forest Cover on Buildable Land			
Zoning Category	**Buildable Area (acres)**	**Forest Cover Coefficient**	**Future Forest Cover on Buildable Land (acres)**
Agriculture	765	.168	128.5
Open urban land	50	.268	13.4
Low density residential	732	.321	235.0
Medium density residential	645	.248	160.0
High density residential	220	.203	44.7
Institutional	88	.134	11.8
Commercial	130	.067	8.7
Total	2,630		602.1

Step 5. Calculate the area of each land cover type for developed land and protected land

Major land cover categories typically include impervious, forest and other pervious cover. The majority of other pervious cover in urban watersheds is made up of turf, although grasslands, crop cover or pasture may be predominant in some watersheds. Open water may be included as another cover category and should be considered unbuildable. An alternative approach is to subtract the area of open water from the total watershed area when doing this analysis. The latter approach is the preferred method when a large waterbody such as a lake or reservoir, dominates the watershed.

Sources of land cover data include:

- Maryland Department of Natural Resources urban tree canopy assessment (also includes impervious surfaces). Communities must pay for acquisition of IKONOS satellite data, but analysis is done for free. Contact Mike Galvin of Maryland DNR for more info.

- Chesapeake Bay Program land cover data (includes 2000 impervious surface data and RESAC land cover data). Available at: http://www.chesapeakebay.net/data/index.htm

- Impervious surface layers (roads, parking lots, etc) and/or forest cover data from local GIS departments (these are often the most detailed layers).

Common problems with deriving current land cover include:

- Lack of available layers such as turf cover, driveways, and sidewalks (Figure 9)
- Insufficient data scale (Figure 10)
- Impervious cover layers are available as lines only (no areas associated with them)
- GIS data is outdated, inaccurate, has an unknown projection, or format is incompatible with GIS software

Cappiella and Brown (2001) provide a method for estimating the area of driveways, sidewalks, and other 'missing' impervious cover layers using aerial photos.

Figure 9. Potential problems with GIS layers include missing sidewalks and driveways

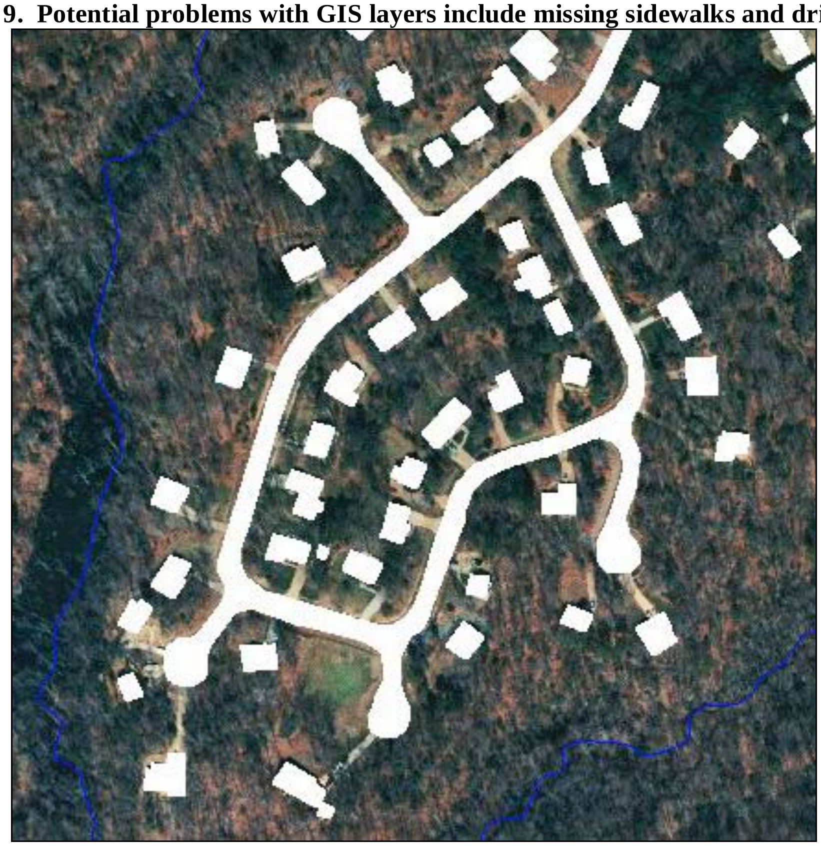
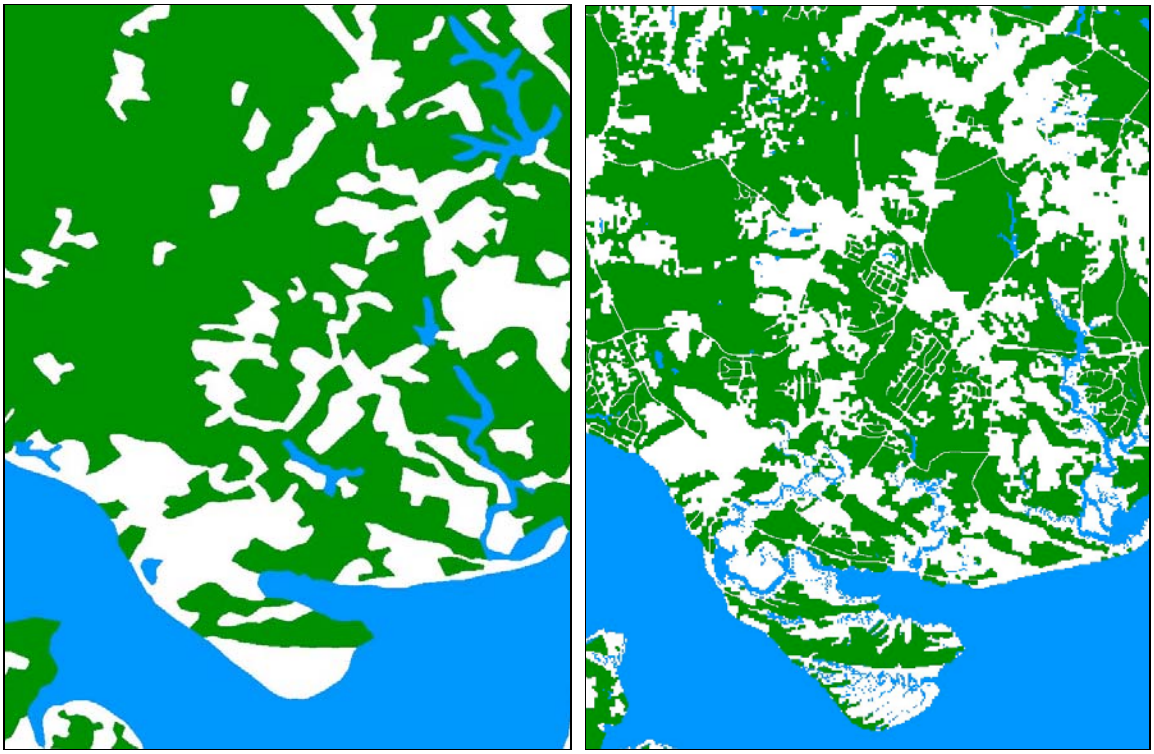
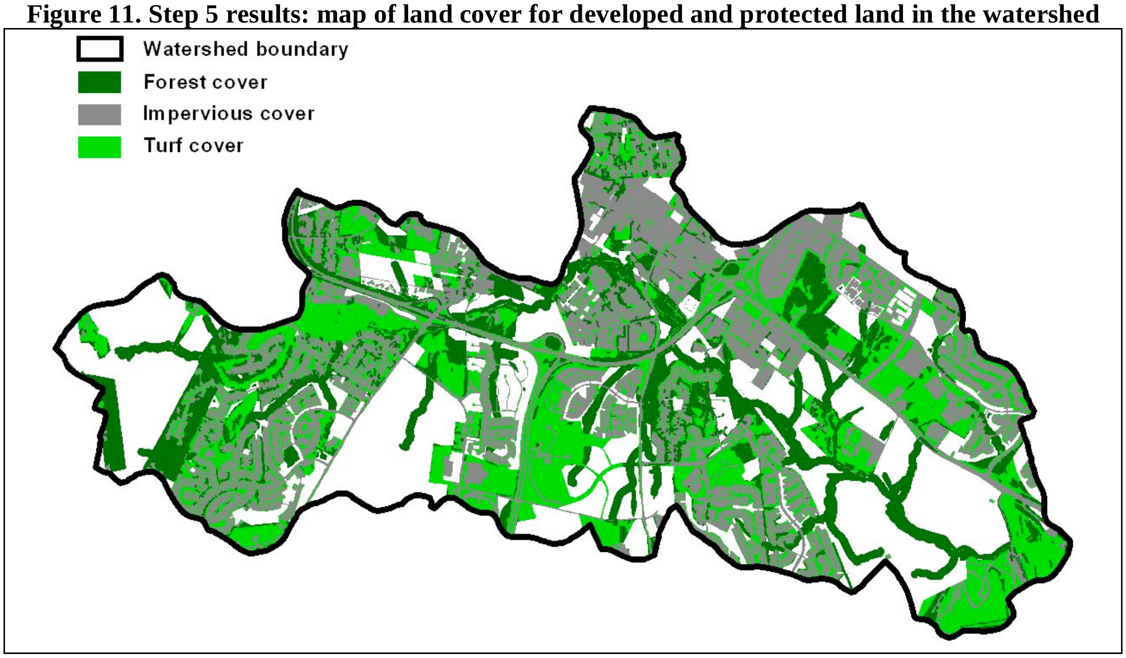


Figure 10. Forest cover data derived from local land use layer (left) is very generalized compared to the more detailed forest cover data derived from satellites (right)



Once adequate data has been obtained for the various land cover types in the watershed, the area of each land cover should be estimated for the developed and protected lands identified previously (Figure 11). This requires intersecting the resulting land cover layer with the developed and protected land layers.

Figure 11. Step 5 results: map of land cover for developed and protected land in the watershed



Step 6: Sum future land cover on buildable, developed and protected land

This step sums future land cover on buildable, developed and protected land (derived during the previous steps) to yield future land cover in the watershed. A spreadsheet (Table 4) is used for this purpose.

Evaluating the effect of watershed protection scenarios on future land cover
To evaluate the effect of various watershed protection scenarios on future land cover, repeat Steps 1-6, and adjust the spreadsheet inputs to reflect the selected watershed protection measures (e.g., reforestation, removal of impervious cover).

Table 5 illustrates how future land cover may change with implementation of the following techniques to conserve or increase forests:

- Conservation of 250 acres of forest through private easements
- Adoption of a local forest conservation ordinance that requires the following forest conservation (or afforestation) thresholds:
    - Low density residential: 40%
    - Medium density and multifamily residential: 25%
    - Institutional, industrial, commercial, and transportation: 15%
- Active reforestation of 200 acres of public turf
- Cost-share program for tree planting on private land that provides enough trees to cover 37.5 acres

Compare the results of the future land cover analyses in Tables 4 and 5. These analyses are for the same watershed, but Table 4 represents the "do-nothing" approach while Table 5 capture implementation of techniques to reduce forest loss. As you can see, future forest cover in the watershed increases from 20% to 24% with implementation of the watershed protection scenario.

Additional Resources

Cappiella, K., Schueler, T., and T. Wright. 2005. *Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed*. Center for Watershed Protection. Ellicott City, MD. Available for free download at www.cwp.org

Cappiella, K., and K. Brown. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed*. Center for Watershed Protection. Ellicott City, MD. Available for $25 from www.cwp.org

Urban Forests Effects Model: www.ufore.org

American Forests: www.americanforests.org