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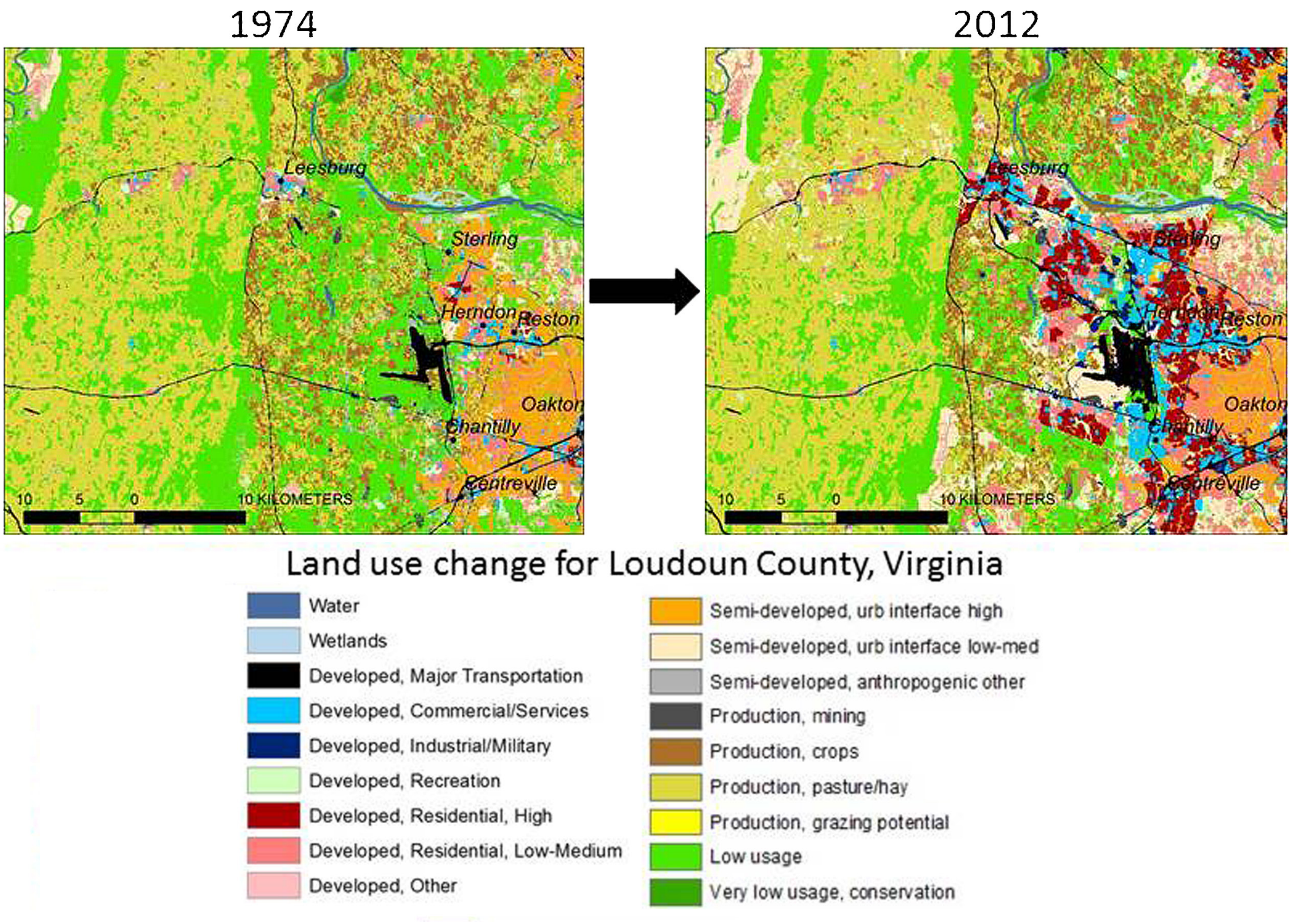
National Water-Quality Assessment Program

U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974–2012



Data Series 948

U.S. Department of the Interior
U.S. Geological Survey

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By James A. Falcone

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SALLY JEWELL, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2015

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Conversion Factors

[Inch/Pound to International System of Units[

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
barrel (bbl), (petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic inch (in^3)	0.01639	cubic decimeter (dm^3)
cubic inch (in^3)	0.01639	liter (L)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)].

Abbreviations

ArcGIS	Geographic information system products suite
ARTBA	American Road and Transportation Builders Association
CBI	Conservation Biology Institute
CDL	Cropland Data Layer (U.S. Department of Agriculture)
CEC	Commission for Environmental Cooperation
CLU	Common Land Unit
CoA	Census of Agriculture
DEM	Digital Elevation Model
DOT	Department of Transportation
EPA	U.S. Environmental Protection Agency
ERS	Economic Research Service (U.S. Department of Agriculture)
Esri	Esri, company name only (formerly Environmental Systems Research Institute)
GAP	Gap Analysis Program (U.S. Geological Survey)
GIRAS	Geographic Information Retrieval and Analysis System (U.S. Geological Survey)
hden	housing unit density
HSIP	Homeland Security Infrastructure Program (U.S. Department of Homeland Security)
HUC	Hydrologic Unit Code
HYDE	History Database of the Global Environment
Landfire	Landscape Fire and Rescue Management Planning Tools (U.S. Geological Survey)
LC Trends	Land Cover Trends program (U.S. Geological Survey)
LEHD	Longitudinal Employer-Household Dynamics (U.S. Census Bureau)
LULC	Land Use/Land Cover (U.S. Geological Survey product of 1970s–1980s)
MassGIS	Massachusetts Office of Geographic Information
NAICS	North American Industry Classification System
NASS	National Agricultural Statistics Service
NAWQA	National Water-Quality Assessment Program (U.S. Geological Survey)
NED	National Elevation Data (U.S. Geological Survey)
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NLCDe (1992)	NAWQA-enhanced National Land Cover Data 1992
NLUD	National Land Use Dataset

NRI	National Resources Inventory (U.S. Department of Agriculture)
NWALT	NAWQA Wall-to-Wall Anthropogenic Land Use Trends
PAD	Protected Areas Database (Conservation Biology Institute)
r^2	coefficient of determination
RMSE	Root Mean Squared Error
SILVIS	Spatial Analysis for Conservation and Sustainability
STATSGO	State Soil Geographic Database (U.S. Department of Agriculture)
TC	Total Cropland
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

U.S. Conterminous Wall-to-Wall Anthropogenic Land Use Trends (NWALT), 1974–2012

By James A. Falcone

Abstract

This dataset provides a U.S. national 60-meter, 19-class mapping of anthropogenic land uses for five time periods: 1974, 1982, 1992, 2002, and 2012. The 2012 dataset is based on a slightly modified version of the National Land Cover Database 2011 (NLCD 2011) that was recoded to a schema of land uses, and mapped back in time to develop datasets for the four earlier eras. The time periods coincide with U.S. Department of Agriculture (USDA) Census of Agriculture data collection years. Changes are derived from (a) known changes in water bodies from reservoir construction or removal; (b) housing unit density changes; (c) regional mining/extraction trends; (d) for 1999–2012, timber and forestry activity based on U.S. Geological Survey (USGS) Landscape Fire and Resource Management Planning Tools (Landfire) data; (e) county-level USDA Census of Agriculture change in cultivated land; and (f) establishment dates of major conservation areas. The data are compared to several other published studies and datasets as validation. Caveats are provided about limitations of the data for some classes. The work was completed as part of the USGS National Water-Quality Assessment (NAWQA) Program and termed the NAWQA Wall-to-Wall Anthropogenic Land Use Trends (NWALT) dataset. The associated datasets include five 60-meter geospatial rasters showing anthropogenic land use for the years 1974, 1982, 1992, 2002, and 2012, and 14 rasters showing the annual extent of timber clearcutting and harvest from 1999 to 2012.

Introduction

This product is a geospatial, 19-class, national land use series. The main product consists of five 60-m raster datasets (ArcGIS grids) for the conterminous United States, which represent the years 1974, 1982, 1992, 2002, and 2012. These time steps coincide with previous selected tabular land use and land cover estimates from the U.S. Department of Agriculture (USDA) Census of Agriculture and National Resources Inventory. A series of 14 supplemental grids are provided, which represent annual estimated timber activity for the period 1999–2012.

The product is not directly derived from imagery; instead, it maps anthropogenic land use changes from existing datasets. The basic method uses a slightly modified version of the National Land Cover Dataset 2011 (NLCD 2011; Jin and others, 2013) that has been recoded to a schema of land uses, and mapped backward in time to develop datasets for the four earlier time periods. The work was completed as part of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program. The name for it is the "**N**AWQA **W**all-to-wall **A**nthropogenic **L**and Use **T**rends" (NWALT).

Work for the project was performed primarily using ArcGIS 10.1 (Esri, 2015) tools and services. The term "grid" in this paper is used to refer to the raster-formatted datasets produced.

While the product's nominal dates are 1974, 1982, 1992, 2002, and 2012, the information for each is derived from data sources that might span multiple years of approximately that time period (see below). For example, it is better to think of the 1992 dataset as "early 1990s" information, as opposed to a snapshot of an exact instant in time.

The rationale for the product is severalfold:

1. NAWQA's Trends studies have a need for consistently derived land cover/use data of the highest feasible spatial resolution from (at least) the 1970s to present for the conterminous United States. Some existing datasets capture some elements of land use; for example, housing unit density (hden) (Hammer and others, 2004) is a measure of residential urbanization at "partial block group" scale, and the Census of Agriculture (CoA) enumerates cultivated land by agricultural use at the county scale. A number of global and other broad-scale time-series products have been produced; however, no dataset currently exists that (a) is a national time series that inclusively maps all land and uses going back at least to the 1970s, (b) has reasonably high spatial resolution, (c) has consistent methodology for all eras, and (d) has reasonable agreement with other major observed datasets (for example, agreeing with agriculture or population change data from U.S. Federal census agencies).

2. Few, if any, land cover time-series products have focused on details of land **use**—how humans use the land—in

essence, the economic function of the land (Campbell, 1996). The intention for this product is to provide as much detailed class information as is feasible with current data (for example, specifying more specific uses within the Developed class).

3. Most broad-scale studies using land cover/use data in the United States are based on the NLCD, which has consistent national datasets for 2001, 2006, and 2011, but not for prior years. This product extends much of the land use utility of the NLCD to previous eras.

The following organizations have produced statewide or region-wide trend statistics for the United States for various periods, scales, and land use types, going back to at least the 1970s:

- U.S. Department of Agriculture (USDA) CoA (U.S. Department of Agriculture, 2014a): 1850–2012, in roughly 5-year increments since the 1950s, county-level enumeration of cultivated land.
- USDA National Resources Inventory (NRI; U.S. Department of Agriculture, 2013): 1982–2010, in 5-year increments, coinciding with CoA years, State-level, statistical survey of land use and natural resource conditions on non-Federal lands.
- USDA Economic Research Service (ERS; U.S. Department of Agriculture, 2014b): 1945–2007 in 5-year increments, coinciding with CoA years, State-level economic surveys.
- USGS Land Cover Trends (LC Trends; Sleeter and others, 2013) group: 1973–2000 (years 1973, 1980, 1986, 1992, and 2000) by Level III ecoregions.

While each of these sources provides potentially useful information, the products do not necessarily agree with each other because of differing methodologies, time periods, class definitions, and goals. Not all of them have data that are comparable over time, even within their own series. For example, the method by which the ERS classifies urban land has changed several times over the years (which they note), in some cases leading to considerable decreases in percent of urban land classified over a period of time for a State, an unlikely real trend. These sources were examined in detail and results were compared to them as part of our validation (see below). The lack of consensus of these data sources regarding land use classifications reflects the fact that land use is typically a more abstract concept than the more straightforward measurement of surface area cover (land cover). For example, a stand of forest in a land cover-only dataset would likely be unambiguously classified as “Forest.” The identical stand, however, could potentially be used for numerous functions: Timber operations, woodland pasture, conservation, urban recreation, and so forth. The classes defined in this product are those for which there is reasonably accurate, consistent, and accessible information, and those that would be most useful to the study of water quality.

Purpose and Scope

The purpose of this report is to describe the methods and data sources for creating a consistent land use map product for five time periods between 1974 and 2012 for the conterminous United States. The goal was to create a product that (a) is consistent as possible with the NLCD 2001–2011 series, (b) agrees with other key data sources such as census-derived information, (c) uses a consistent method for all years, and (d) represents land use as accurately as possible. The focus of the product is to capture major land use trends.

Methods

The basic land use classification method had three broad steps: (a) Make a slightly modified version of the NLCD 2011 for use as a base grid, (b) recode it to a schema of land uses, and (c) remap those uses by incorporating data from a variety of sources, backward in time every 10 years, to develop datasets with identical spatial extent and classifications for 1974, 1982, 1992, and 2002. The country was divided into 12 major regions (fig. 1) for processing purposes, based on USDA ERS Major Land Use regions (Department of Agriculture, 2014b). Some elements of change, namely the Developed and Agriculture classes, were constrained by regional statistics, as described below.

Data Sources

A list of sources used to develop the datasets is given below. The list is organized to give the name, year(s), spatial resolution or scale, reference of the source, general type of information used from the source, and a Web address for obtaining the data, where available. A more detailed description of how the source was used is given later in this document.

- NLCD 2011, April 2014 version, 30 meters (m) (Jin and others, 2013):
  - Provides basis of information for base year 2012 classification.
  - See http://www.mrlc.gov/nlcd2011.php.
- USDA Census of Agriculture, 1974–2012, State and county-level data (U.S. Department of Agriculture, 2014a):
  - Primary information for cultivated crops and pasture/hay changes.
  - See http://www.agcensus.usda.gov/Publications/Historical_Publications/ (1974–2002), and

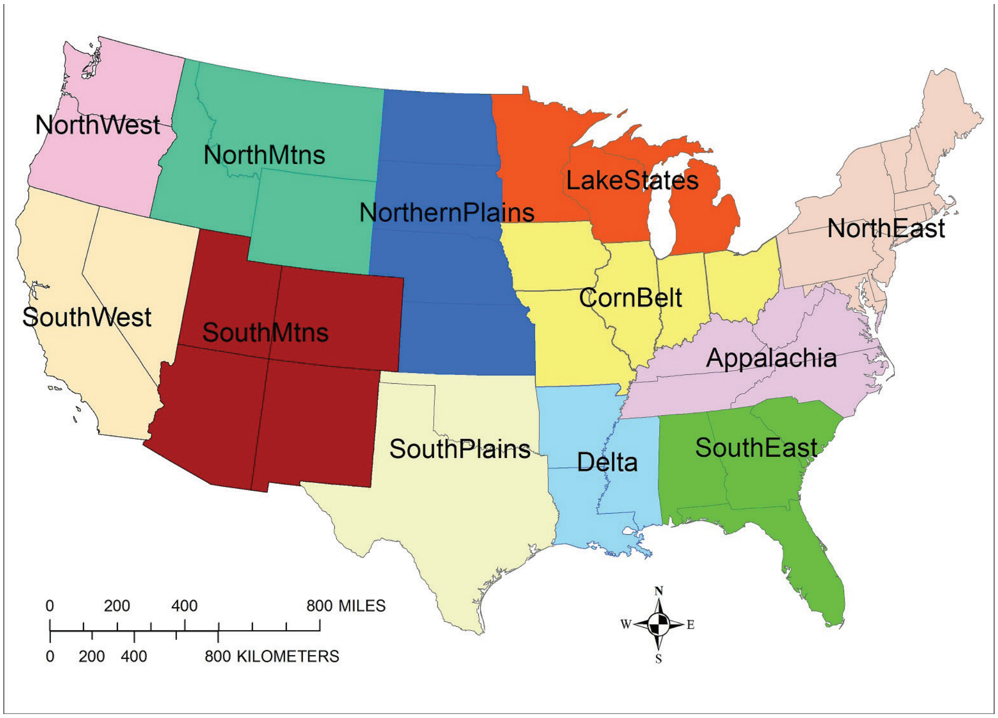

Figure 1. Major regions used for data processing of the NWALT product (NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends).

  http://www.agcensus.usda.gov/Publications/2012/ (2012).

- U.S. Census 2010 hden, provided by GeoLytics Inc., block group scale (GeoLytics, 2012):
  - Information for 2012-era urban mapping.
  - See http://www.geolytics.com/.
- Spatial Analysis for Conservation and Sustainability (SILVIS) Lab housing unit density, 1970–2000, partial block group scale (Hammer and others, 2004):
  - Primary information for mapping urban change. (See Note 1 in appendix 1 for more detail.)
  - See http://silvis.forest.wisc.edu/maps/housing/pbg_1940_2030.
- History Database of the Global Environment (HYDE) 3.1 1970–2005 decadal cropland and pasture 9-km (5 ‘) data (History Database of the Global Environment, 2013):
  - Supplemental mapping of agriculture changes.
  - Estimates of agricultural changes at regional scale.
  - See http://themasites.pbl.nl/tridion/en/themasites/hyde/.
- USDA/USGS soil capability class, 1:250k (Baker and Capel, 2011):
  - Maps soil classes as to their suitability for cultivated crops.
  - Facilitates identifying probable crop versus pasture and hay locations.
  - Raster dataset based on STATSGO data processed from Baker and Capel (2011).
- USGS National Elevation Data (NED)-derived slope, 100 m (U.S. Geological Survey, 2014a):
  - Facilitates identifying probable crop vs pasture/hay locations.
  - See http://ned.usgs.gov/.
- USGS Landfire (Landscape Fire and Rescue Management Planning Tools), 1999–2012 annual disturbance grids, 30 m (U.S. Geological Survey, 2014b):
  - Provides information about timber and forest cutting.
  - See http://www.landfire.gov/.
- National Inventory of Dams (NID) point locations, 2013 (U.S. Army Corps of Engineers, 2013):
  - Provides information about reservoir construction dates (water bodies being created).
  - See http://geo.usace.army.mil/pgis/f?p=397:1:0.
- Dam removal point locations, 1912–2013 (American Rivers, 2014):
  - Provides information about dam removal dates (water bodies being removed).

- See http://www.americanrivers.org/initiatives/dams/dam-removals-map/.

- NLCD 2006 and 2001 land cover/use, 30 m: (Fry and others, 2011; Homer and others, 2007; U.S. Geological Survey, 2014c):
  - Supportive data for numerous steps, particularly historical-era pixel placement.
  - NLCD 2006 and 2001 are from "2011 versions" rereleased April 1, 2014.
  - See http://www.mrlc.gov/.
- NLCD "Enhanced" 1992 (NLCDe 1992), 30-m land cover/use (Nakagaki and others, 2007):
  - Supportive data for numerous steps, particularly historical-era pixel placement.
  - The NLCDe 1992 (Nakagaki and others, 2007) is a "NAWQA-enhanced" version of the regular NLCD 1992. The primary change was to recode some pixels to urban and agriculture classes, based on earlier-era land use data.
  - See http://water.usgs.gov/GIS/metadata/usgswrd/XML/nlcde92.xml.
- USGS Geographic Information Retrieval and Analysis System(GIRAS) 1970s land cover/use (Price and others, 2007):
  - Supportive data for numerous steps, particularly historical-era pixel placement.
  - Manually derived data representing primarily 1970s (see Note 2).
  - See http://pubs.usgs.gov/ds/2006/240/.
- Protected Areas Database, PADUS_CBI_Edition V2 (Conservation Biology Institute, 2013):
  - Conservation area information: land set aside for natural areas or wildlife protection.
  - Supplemented with establishment dates researched by our project.
  - See http://consbio.org/products/projects/pad-us-cbi-edition.
- USGS historical oil/gas well locations, aggregated to square mile blocks, 1970–2005 (Biewick, 2006):
  - Provides information about proximity to industrial and extraction activity.
  - See http://pubs.usgs.gov/dds/dds-069/dds-069-q/text/cover.htm.
- U.S. Environmental Protection Agency (EPA) point locations of mining, landfill, metal, and nonmetal processing sites, and oil/gas exploration sites, from Envirofacts MultiSystem Query (U.S. Environmental Protection Agency, 2014a):
  - Provides information about proximity to industrial and extraction activity.
  - See http://www.epa.gov/enviro/.
- NHD (National Hydrography Dataset) 1:24k water bodies (U.S. Geological Survey, 2012) and NHDPlus V2 streamlines (U.S. Environmental Protection Agency, 2014b):
  - Facilitates identifying potential grazing areas.
  - See http://nhd.usgs.gov/data.html and http://www.horizon-systems.com/nhdplus/.
- USDA NRI (U.S. Department of Agriculture, 2013), 1982–2012 and ERS (U.S. Department of Agriculture, 2014b), 1974–2007: State-level statistics and USGS LC Trends (Sleeter and others, 2013), 1973–2000, ecoregion statistics:
  - Provide regional statistics of land cover/use for comparison checking and validation.
  - NRI - See http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167354.pdf.
  - ERS - See http://www.ers.usda.gov/data-products/major-land-uses.aspx.
  - USGS Land Cover Trends - See http://landcovertrends.usgs.gov/.
- USDA Cropland Data Layer (CDL) 2009, 56 m, updated version, downloaded November 2014 (U.S. Department of Agriculture, 2014c):
  - Supplemental information about potential grazing, as described below.
  - See http://www.nass.usda.gov/research/Cropland/SARS1a.htm.
- Homeland Security Infrastructure Program (HSIP) 2012 land use polygons (n ~ 100,000), lines, and points (Homeland Security Infrastructure Program, 2012):
  - Primarily used for mapping urban detail.
  - Includes day-versus-night 90-m population rasters.
  - At present, dataset restricted to Federal Government agencies and partners.
- Esri USA landmark (important land use features) polygons (n ~ 80,000) and lines (Esri, 2014a):

    - Used for mapping urban detailed classes.
    - See http://www.arcgis.com/home/item.html?id=6ffa5cb05c3b4978bd96b8a4b416ffa6.
- David Theobald national land use dataset (Theobald, 2014):
    - Guiding format for classification schema and supportive data for non-residential urban classes.
    - See http://www.csp-inc.org.
- Census 2000 roads, provided by GeoLytics, Inc. (GeoLytics, 2001):
    - Supportive data for 2002-era road changes.
    - See http://www.geolytics.com.
- USGS 1992–2001 30-m Retrofit Land Cover Change Product (U.S. Geological Survey, 2014c):
    - Part of NLCD program data: supportive information for 1992-era Developed changes.
    - See http://www.mrlc.gov/nlcdrlc.php.
- Massachusetts State historical land use for 1971, 1985, and 1999, 1:25,000 (Massachusetts Office of Geographic Information (MassGIS); State of Massachusetts, 2014):
    - Used for validation.
    - See http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/lus.html.
- U.S. Department of Commerce Census Bureau block-level employment data (U.S. Department of Commerce, 2014):
    - Supportive data for Commercial/Industrial classes.
    - See http://onthemap.ces.census.gov/.
- U.S. Department of Commerce Census Bureau 2010 block boundaries (U.S. Department of Commerce, 2012):
    - Used to map employment data.
    - See ftp://ftp2.census.gov/geo/tiger/TIGER2010BLKPOPHU.
- In-house derived land use polygons database (n ~ 45,000), in-house-derived conservation areas change data (n ~ 1,400), and in-house derived reservoir change data polygons (n ~ 2,900), all described below.

Modifying the NLCD 2011 for Use as a Base Grid

The changes made to the NLCD 2011 to use as a base grid were resampling from the original 30-m to 60-m, thinning rural roads, and reclassifying a small number of agriculture pixels in highly urban areas.

Resampling to 60 m.—Everything in this project was processed at 60 m (nearest neighbor resampling), primarily to allow for reasonable processing time, improve portability, and eliminate problems from some software limitations on large datasets.

Thinning rural roads.—The NLCD 2001–2011 series typically “burned in” all roads, regardless of whether or not they would take up the majority of a 30-m pixel (most minor roads are typically 8–10 m wide). One can make the case that in some applications this is beneficial in that it helps to quantify scattered ex-urban residential areas or impervious surfaces that are otherwise not captured by 30-m Landsat imagery. However, it also may have a confounding effect in that it typically makes it more difficult to distinguish the amount of actual “urbanization”—in the sense of the built environment of central places—in watersheds. For example, watersheds with virtually no human presence but that had numerous farming or minor roads in them were more difficult to distinguish from watersheds that had low levels of actual urbanization (that is, presence of human population). Furthermore, other major land cover projects have similarly produced “reduced roads” versions of land cover (for example, Irani and Claggett, 2010). Therefore, housing density and other ancillary information were used to filter out rural roads, as follows.

First, graduated zones of housing density were created over the landscape. Where hden was >62 units/km^2 (see Note 3) or an NLCD 2011 Developed pixel coincided with an area of known current non-residential Developed land use (for example, schools, industrial areas, oil/gas fields, and so forth), none of the Developed pixels were changed. For hden zones less than 62, a graduated and increased percentage of pixels were recoded to a non-Developed class. In areas of 0 hden and no known non-residential urban uses, 95 percent of pixels were recoded. The vast majority of pixels recoded represented minor roads. Major roads were kept, regardless of where they were located (see Note 4). In this way, the entire Developed class more closely represents true urban uses than the published NLCD 2011.

The overall effect is a significant, but for many purposes, beneficial reduction of the number of pixels classified as Developed in highly nonurbanized areas not related to commercial and industrial activities (fig. 2). For example, in the five-State Appalachia area, the percentage of pixels classified as Developed land (NLCD classes 21–24) in the original NLCD 2011 is 8.92 percent. In the NWALT’s 2012 dataset, the percentage of pixels classified as Developed is 6.19 percent (classes 21–27) and Semi-Developed is 8.29 percent (classes 31–33). The lower percentages of Development are actually more in line with how several other products estimate the Developed class. For example, extrapolating

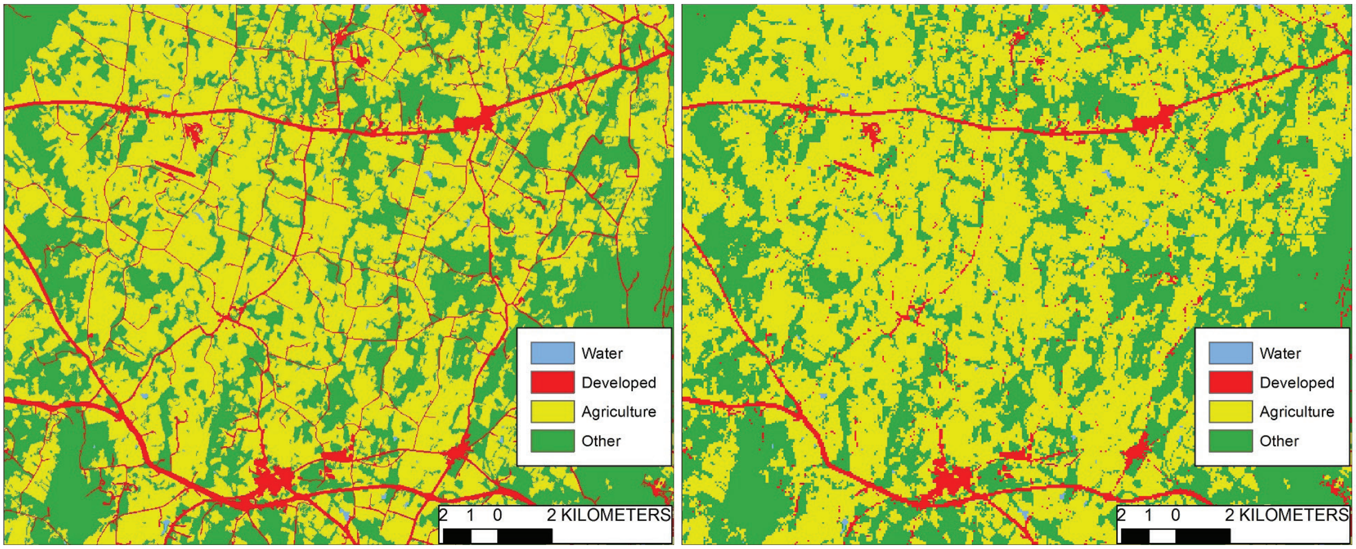

Figure 2. Rural roads thinning. Left-side panel shows NLCD 2011 (Jin and others, 2013). Right-side panel shows NWALT base grid, after rural roads thinning. Area shown is a portion of Fauquier County, Virginia (NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends).

the NLCDe 1992 dataset (NAWQA-enhanced NLCD 1992, which itself added urban pixels to the regular NLCD 1992) based on hden changes, one might make a reasonable estimate of what 2012 Developed would be for a region. Doing so for Appalachia, the Developed class would increase from 4.81 percent to an estimated 5.80 percent, far below what the NLCD 2011 represents. Similarly, extrapolating the 250-m 2005 Commission for Environmental Cooperation (CEC) North American land cover dataset (Commission for Environmental Cooperation, 2014) based on hden, the estimate for Developed for Appalachia for 2012 would be only 4.70 percent. The reduced percent Developed in the NWALT 2012 grid, therefore, still seems reasonable, and more like a representative average of possible land cover/use estimates for the period. Note also that the Semi-Developed classes in the NWALT structure provide additional information about urban influences and information not present in the NLCD.

The rural-road pixels that were changed were reclassified with what the land likely was without their presence. This was done primarily using **focalmean** commands in ArcGIS, which essentially map majority presence of nearby pixels. A rural farming road would therefore likely be reclassified to agriculture pixels. The overall effect was to slightly increase the percentages of all other land cover types in the starting-point base grid.

Reclassifying a small number of agriculture pixels in highly urban areas to a Developed class. A very small number of NLCD agriculture pixels (NLCD classes 81 and 82) were recoded to a Developed class in our base grid where hden exceeded 1,000. This was based on the visual observation that agriculture pixels in areas of such very high density urbanization were almost always in reality an urban use, such as school playing fields or urban parks. This change had a very minor effect and only affected 10,000 of 497,000,000 total 60-m agriculture pixels.

Classes

This product primarily categorizes types and intensity of land uses, with classes conceptually similar to those proposed by Theobald (2014). Theobald implemented a hierarchical 79-class land use schema, and produced a national 30-m raster for the current era (approximately 2011–2013) with 61 of the classes populated. Theobald's product, termed the National Land Use Dataset (NLUD), is based on a composite of classification schemas, primarily that of Anderson and others (1976) and the North American Industry Classification System (NAICS; U.S. Department of Commerce, 2015). However, the thematic detail of many of the classes (for example, "Orchards") is not readily reproducible with current data going back to the 1970s at a sub-county scale. Therefore, this product uses a somewhat different class structure that is more readily reproducible back in time, but still focused on anthropogenic uses. This product contains six broad classes ("Level 1"), and 19 subclasses ("Level 2") (table 1). Detailed class descriptions are provided in appendix 2. As in the Theobald schema, the aquatic classes (Water and Wetlands) are primarily representations of "cover," while all other classes are representations of "use." (Water is also partly a use class in that it incorporates water-body changes from reservoir construction and dam removals since 1974.) Because the NAWQA Program studies aquatic systems, it is valuable to have explicit representations of those cover classes.

Table 1. Product classes and subclasses of the NAWQA Wall-to-Wall Anthropogenic Land Use Trends dataset (NAWQA, U.S. Geological Survey's National Water-Quality Assessment Program).

1. Water	**4. Production**
11. Water	41. Mining/Extraction
12. Wetlands	42. Timber and forest cutting (1999–2012 only)
2. Developed	43. Crops
21. Major Transportation	44. Pasture/Hay
22. Commercial/Services	45. Grazing Potential
23. Industrial/Military	**5. Low Use**
24. Recreation	50. Low Use
25. Residential, High Density	**6. Very Low Use, Conservation**
26. Residential, Low-Medium Density	60. Very Low Use, Conservation
27. Developed, Other	
3. Semi-Developed	
31. Urban Interface High	
32. Urban Interface Low Medium	
33. Anthropogenic Other	

As in the NLUD (Theobald, 2014), aside from **Water**, the Level 1 classes broadly distinguish the major settings in which humans use and interact with the land:

Developed: The built environment; settings where residences, employment, and recreation predominate.

Semi-Developed: The "near-built" environment; settings that are in close proximity to Developed lands and (or) are partially used for the same purposes.

Production: Settings in which natural resources are produced (Agriculture) or removed (Mining and Timber).

Conservation: Land set aside for natural areas or wildlife protection.

Low Use: Land not discernible as being in any of the above categories; that is, there is no evidence of regular human usage.

Information from USGS Historical and Other Land Use/Land Cover Datasets

There have been three primary general purpose land cover/use datasets produced by the USGS for the Nation over the last 35 years at fairly high resolution—the GIRAS (1970s; Price and others, 2007), the NLCD 1992 (early 1990s; U.S. Geological Survey, 2014c), and the NLCD01–06–11 (2001–2011; Jin and others, 2013). (See Note 2 regarding the GIRAS). It is clear there are methodological differences between the three series and they are not directly comparable "as is." However, there are also great similarities among them, and each provides quite a lot of information about each era. In examining them, it is clear that there are large areas of the United States that are, and have stayed, an unambiguous type over the last 35 years, and for which the products all agree, particularly at Anderson Level 1 (Anderson and others, 1976). For example, large areas of national forest are classified as "forest" in all of those products; New York City is classified as "Urban" in all of those products; very large areas of the western United States are classified as "Shrub/Grassland" in all of those products; almost all the pixels representing large water bodies are classified as "Water," and so forth.

Our reasoning was that if there was perfect agreement at Anderson Level 1 (Water, Urban, Barren/Mining, Forest, Shrub/Grassland, Agriculture, Wetlands, and Ice/Snow) among the GIRAS, NLCDe 1992, and NLCD 2011, those pixels were less likely to have changed in reality over that period and could represent a "low-probability change" mask—an overlay that could mask out some parts of the processing. The areas of perfect agreement among those three datasets represent roughly 60 percent of the United States. We first visually inspected many examples of these pixels (see Note 5), in part, using GoogleEarth© historical imagery (Google, 2013) and, in part, using online historical Landsat (Esri, 2014b). Virtually 100 percent of them appeared to have not changed Anderson Level 1 classification over that period. They were next compared to a high-quality, manually derived land use dataset spanning 28 years (1971–1999) for the State of Massachusetts (MassGIS; State of Massachusetts, 2014). For the State of Massachusetts, more than 95 percent of the low-probability mask pixels did not change between 1971 and 1999. Pixels outside the mask had a roughly four times higher chance of change. This led us to conclude that little error would be introduced by maintaining them as a mask for some elements of processing. Namely, in this dataset, the pixels in this mask are excluded from changing Level 1 class in the Developed and Agriculture processing shown below. They may still change as a result of manual polygon processing, and may change Level 2 class. The processing for all change methods is described below and in appendixes 3 and 4.

Method for Building Datasets

Once the 2012 base grid was built as described above, it was recoded to the schema of 19 land use classes presented above. A stepwise approach was then used to sequentially develop each grid so that after the 2012 base was developed, the 2002 grid was developed from that, then 1992, and so forth. Each grid was thus built from that of the year that was previously processed.

Coding 2012 Land Uses

The following is a brief description of how the 2012 base grid was reclassified to the NWALT land use structure by class. Appendix 3 provides a more detailed stepwise logic flow for the process.

11 - Water: Identical to NLCD 2011 water (NLCD class 11), with the exception of a very small number of Water pixels added where minor roads were removed, and they were over a water body (for example, a minor road that was a bridge).

12 - Wetlands: The Wetlands class in this entire series is a constant mask (area of no change) of "core wetlands," comprised of pixels that were classified as Wetlands in all three of the NLCD 2011, NLCD 2001, and the NLCDe 1992 datasets. Because there is not very consistent or spatially explicit national information about wetlands for the time period of this dataset, it is believed that having a constant wetlands mask—pixels that almost certainly represented Wetlands over the life of this data series—is preferable to excluding it as a class. Options for modeling wetlands changes for future versions of this product are under consideration.

21–27 - Developed: Pixels that were classified as Developed (21–24) in the NLCD 2011, and that remained after the rural-roads thinning described above. Developed Level 2 classes were coded following the method described in Falcone and Homer (2012), and were based on six primary data sources: HSIP lines (roads and railroads), land use polygons, and day-versus-night population rasters (Homeland Security Infrastructure Program, 2012); Esri landmark polygons (Esri, 2014a) and lines; hden (Hammer and others, 2004); employment data (U.S. Department of Commerce, 2014); Theobald (2014) national land use data; and in-house-derived land use polygons (see Note 6). Classes were distinguished primarily on (a) whether or not the pixel intersected a known current land use polygon or line (for example, a hospital, park, industrial area, and so forth), (b) the ratio of daytime to nighttime population, (c) type and intensity of block-level employment (see Note 7), and (d) hden.

31 - Semi-Developed, Urban Interface High: Any NLCD 2011 pixel that was not in a Water, Developed, Production, or Conservation class, and was in a highly urban area. A highly urban area was defined as hden >500 units/km^2 or in an urban core area (see Note 8).

32 - Semi-Developed, Urban Interface Low Medium: Any NLCD 2011 pixel that was not in a Water, Developed, Production, or Conservation class, was in an area with a hden between 16–500 units/km^2, and was not in a U.S. Geological Survey Gap Analysis Program (GAP) status class 1, 2, or 3 in the Protected Areas Database CBI Edition V2 (Conservation Biology Institute, 2013). This class maps primarily suburban and ex-urban areas located amongst and proximal to Developed lands.

33 - Semi-Developed, Anthropogenic Other. Any NLCD 2011 pixel not in any other use class, but had very probable non-residential anthropogenic use, based on agreement of GIRAS and current-day uses. These include primarily recreation or industrial uses not captured by the NLCD 2011 as Developed. This is a minor class, comprising much less than 1 percent of any region's pixels.

41 - Production, Mining/Extraction. Any pixel that was barren (31) in the NLCD 2011, and intersected a mask of mining/extraction areas developed for this project (see Note 9).

42 - Production, Timber and forest cutting. Any pixel that would otherwise be coded as NWALT class 50 (no apparent land use), intersects a Landfire (U.S. Geological Survey, 2014b) 2012 area with a disturbance code of "clearcut," "thinning," "harvest," "mastication," "other mechanical," or "unknown," has very low evidence of urbanization or agriculture, and the pixel had been in a forest class in any one of GIRAS, NLCDe 1992, NLCD 2001, or NLCD 2011. At present, the Timber class is maintained as a series of separate annual grids to avoid possible confusion with pre-1999 years, when Landfire was not available. These are national 60-m grids with all pixels classified as "Timber" or "Not Timber."

43 - Production, Crops: Any pixel that was classified as Cultivated Crops (82) in the NLCD 2011. A small number of Crop pixels exist in this product that did not exist in the NLCD, where minor roads were removed and the proximal land use was crops.

44 - Production, Pasture/Hay: Any pixel that was classified as Pasture/Hay (81) in the NLCD 2011. A small number of Pasture/Hay pixels exist in this product that did not exist in the NLCD, where minor roads were removed and the proximal land use was pasture/hay.

45 - Production, Grazing Potential: There are certainly areas in the United States that have seasonal or occasional grazing that are part of the NLCD grassland and shrubland categories, although most users do not typically categorize these classes as Agriculture. In the Census of Agriculture data, total amount of pastureland + hay-alfalfa is typically greater than what is represented by the NLCD in its class 81. This project attempts to map those areas where grazing is most likely as follows: Any pixel that is classified as Forest (41–43), Shrub (52), Grassland (71), or Wetlands (90, 95) in the NLCD

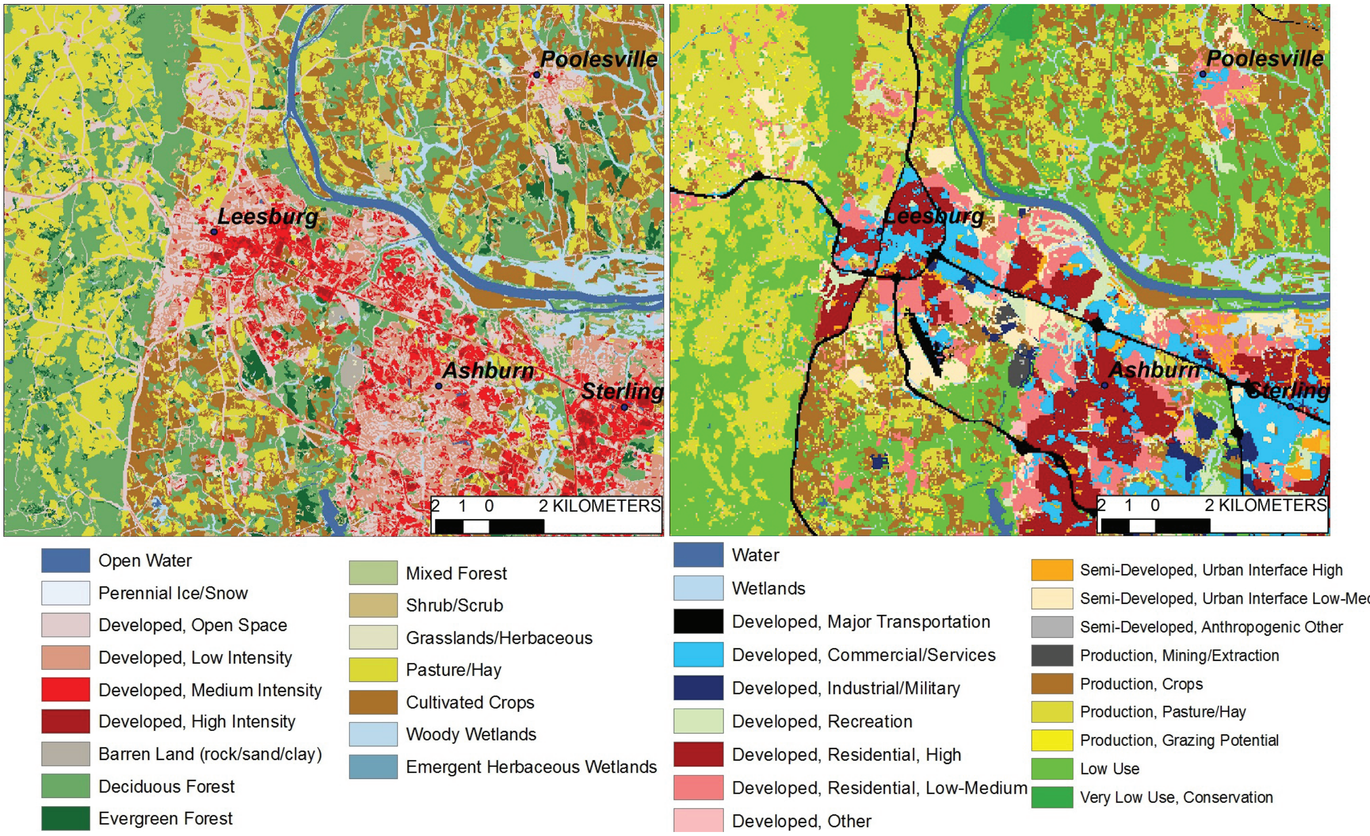

Figure 3. Recoding to land uses. Left panel shows NLCD 2011 (Jin and others, 2013). Right panel shows NWALT 2012 grid, after recoding to product land use schema. Area shown: Portions of Loudoun County, Virginia, and Montgomery County, Maryland (NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends).

2011, that would otherwise be coded as NWALT class 50 (no apparent other land use); pixel is within 1 km of a water body (NLCD or NHD 1:24k water body) or within 500 m of a streamline; slope is <30 percent, and was in a Pasture/Hay class in the NLCDe 1992 **and** the CDL 2009; has hden <124, and is not on a military base, national park, or similar unlikely grazing area.

In this paper, when referring to "Agriculture" in general (for example, in validation), we have taken the sum of classes 43 and 44, primarily to be as consistent as possible with the NLCD. However, class 45 represents in essence a "swing" class; users may or may not wish to combine it with classes 43 and 44 with representing Agriculture for their purposes.

50 - Low use: Any NLCD 2011 pixel not classified in another class; that is, there is no obvious other land use.

60 - Very Low Use, Conservation: Any NLCD 2011 pixel not identified as having another land use, and in a GAP status 1 area ("most protected"; see Note 10) in the Protected Areas Database CBI Edition V2 (Conservation Biology Institute, 2013). Assumed very low human usage.

A sample of the results of the above process is given in figure 3.

Mapping Changes from 2012 to Previous Time Periods

Once the 2012 grid was coded to the NWALT schema, the previous eras' grids were built in sequence. The method followed a stepwise approach, essentially adding a series of masks for each class (fig. 4). At the end, those pixels for which no obvious land use can be identified were put in class 50, Low Use. Very broadly, the steps observed the following sequence, where Water is masked first, then, Wetlands, then Conservation, and so forth:

Water → Wetlands → Conservation → Developed (Level 1) → Mining → Agriculture (Level 1) → Agriculture (Level 2 – Crops versus Pasture/Hay) → Grazing Potential → Semi-Developed → Developed (Level 2) → Low Use

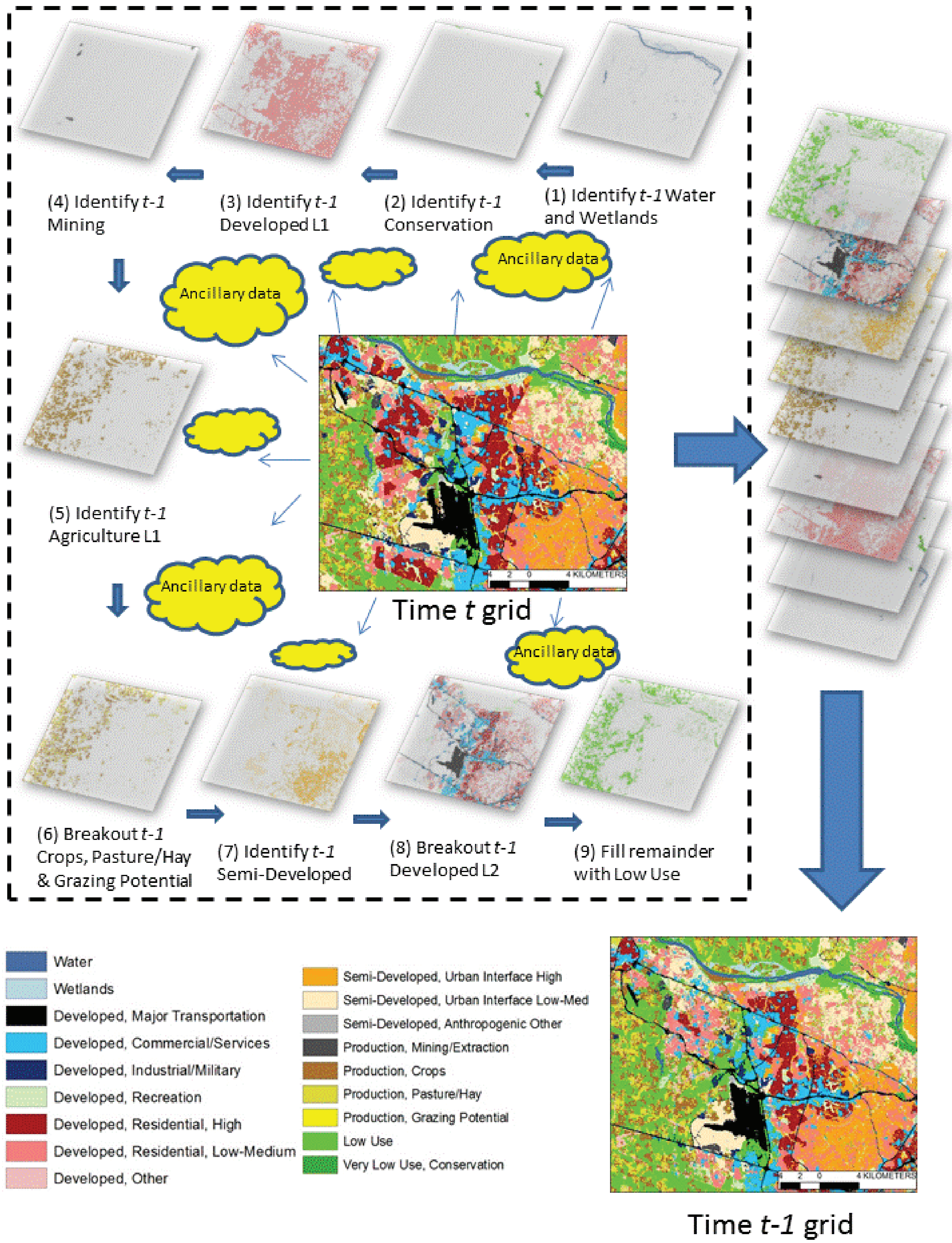

Figure 4. General processing flow for mapping a prior time period. Time t grid (for example, 2012) is processed against ancillary datasets to identify changes by class to produce grid for time t-1 (for example, 2002). Area shown is Loudoun County, Virginia, 2012→2002.

The Timber class is processed as a post-production activity, as described below.

The following gives an overview description of how each of these classes was processed. Appendix 4 provides a more detailed stepwise logic flow for the process.

1. **Water:** As preparation for this step, we first manually created two datasets:

   a. We examined about 4,100 reservoir locations that were constructed since 1974 and had storage greater than 150 acre-feet, based on the Completion Date and Normal Storage attributes, respectively, from the 2013 NID (U.S. Army Corps of Engineers, 2013). If a water body was created in that year, based on visual examination of imagery and (or) historical land cover datasets, a polygon was digitized around it and the date recorded as an attribute of the polygon. Run-of-river dams where no significant water body was created were ignored. This captured 2,925 major water bodies that had changed.

   b. We examined 540 dam-removal locations that occurred from 1975 to 2011 (American Rivers, 2014). Based on historical datasets (GIRAS, NLCDe 1992), if a water body existed prior to the dam-removal year, we digitized the area of the water body. This captured 72 water-body changes.

   The Water class can change in two ways in this data series: (a) A water body from an earlier year grid being “removed” based on the year of completion in the above reservoir-creation polygons, or (b) a water body from an earlier year being “created” based on the removal year of one of the dam-removal polygons. For example, if a reservoir was built in 1985 and it had been determined that a water body was created (a polygon had been digitized), those water pixels are reclassified in the 1982 and 1974 grids to non-water. Similarly, if a dam was removed in 1985 and a water body existed in the GIRAS but not in the 1992 grid, then those pixels are classified to Water in the 1982 and 1974 grids. Because we suspect the NID does not completely capture all water-body changes for recent years, for water-body removals for the period 2002–2012, we also accepted some NLCD 2001–2011 water changes (see Note 11). This was done to keep this dataset as consistent as possible with the NLCD 2001–2011, but still adhere to the method of this dataset.

   When a Water pixel was reclassified to non-water in an earlier year, it was assigned an interim class based on grid values of the appropriate historical land cover/use dataset (GIRAS, NLCDe 1992, NLCD 2001) for that time period. For example, a reservoir-water pixel in 2002 that changed to non-water in 1992 would be assigned an interim classification of Agriculture if the NLCDe 1992 indicated agriculture. That interim classification could then change based on subsequent processing; for example, a further change to Low Use was possible in the Agriculture processing, as described below.

2. **Wetlands:** As noted above, the Wetlands class of this data series is a constant mask, based on pixels that were coded as Wetlands in all three of the NLCD 2011, NLCD 2001, and NLCDe 1992 datasets. The rationale for doing so is discussed above.

3. **Conservation:** As preparation for this step, we first manually researched the Establishment Date for the 1,418 largest GAP Category 1 (“most protected” category) polygons of the Protected Areas Database CBI Edition V2 (see Note 12). These were all Category 1 polygons with area >2,500 acres (about 10 km^2). An establishment date was successfully identified for 90 percent of these polygons. These are National Parks, Wilderness Areas, National Preserves, Wild and Scenic Rivers, and Research Natural Areas, among others.

   In this data series, Conservation changes occur at the area’s establishment date. For example, if a Wilderness Area was established in 1984, then those pixels will be classified as Conservation in the NWALT 1992, 2002, and 2012 grids, but non-Conservation in 1982 and 1974. If the establishment date was pre-1975 or could not be found, that area was classified as Conservation for all years of this product.

   As with Water above, when a Conservation pixel was reclassified to non-Conservation in an earlier year, it was assigned an interim class based on grid values of the appropriate historical land cover/use dataset for that time period. That interim classification could then change based on subsequent processing.

4. **Developed (Level 1):** The Developed class (“urbanization”) is modeled primarily from housing density change (Hammer and others, 2004), with additional information provided about non-residential uses from current and historical land cover datasets. The overall amount of urbanization modeled backward is based on an equation of the relationship of housing density and the change in NLCD 2011–2001 Developed for that specific region (regions shown in fig. 1). For example, for the NorthEast region, the NWALT 2012 grid has 8.92 percent classified as Developed. Based on hden changes, the target goals for 2002, 1992, 1982, and 1974 were 8.47, 8.09, 7.65, and 7.18 percent, respectively. Two assumptions are made in this process: (a) That Development is irreversible once it occurs. (See rationale for this assumption in Caveats and Assumptions section below.) That is, Developed pixels in 1974 will always be a subset of Developed pixels in 1982, which in turn are a subset of Developed pixels in 1992, and so forth; and (b) that the relationship of hden change to Developed lands change does not change substantially over time within a region. That is, if an *x* change in hden translates to a *y* change in Development for the latest

10 years, then that relationship will roughly be the same for previous eras.

The method used to achieve these target goals for each region was to create graduated zones of hden (as was done for the roads-thinning step), then a graduated number of pixels were marked for reclassification to a non-Developed class from each zone until the goal was achieved. The process uses a heuristic starting point of the number of pixels to be selected by zone, which is then adjusted so that the number of pixels reclassified is tailored to that region and year. The selection of which pixels are to be reclassified is guided by surfaces representing three parameters: Magnitude of hden change, the hden for the year in question, and whether or not the pixel was in a Developed class in a historical land cover/use dataset. This was further facilitated by a random number-generated grid, which allowed selection of a specific number of pixels within those subgroups. Non-residential changes (for example, an industrial area) are likewise incorporated based on the historical land cover/use datasets, as well as estimates about the magnitude of major road changes over broad regions (American Road and Transportation Builders Association, 2014) (see note 13). The overall Developed change, both residential and non-residential, is assumed to approximate the change indicated by the target goal number.

At the end of this process, a broad manual review was done of each region, comparing the NWALT result to historical imagery and land cover datasets. In some cases, manual adjustments using correction polygons were made as a result of this.

As with Water and Conservation above, when a Developed pixel was reclassified to non-Developed in an earlier year, it was assigned an interim class based on the appropriate historical land cover/use.

5. **Mining/Extraction:** As noted above, 2012 Mining/Extraction is based on the intersection of NLCD 2011 class 31 pixels with this project's current-day mask of probable surface-mining areas and oil/gas development. For years before 2012, this mask changes in two ways: (a) Pixels from GIRAS mining gradually replace NLCDe 1992 mining going back in time, and (b) oil/gas polygons from the USGS historical oil/gas data series are taken from the appropriate earlier time period. For 2002, NLCD 2001 class 31 pixels are accepted as new locations to intersect with the 2002 mining mask, and for previous eras, overall magnitude of change is based on the USGS Land Cover Trends program's (LC Trends) Mining for that region (see Note 14). The result is that for 1992–1974, the regional trend will approximate the USGS LC Trend, and pixel locations of mining will be closer to GIRAS mining locations, going back in time.

6. **Agriculture (Level 1):** For the years 1974–2002, Census of Agriculture (CoA) data were provided by the USGS Century of Trends project (Stets and others, 2012), from Waisanen and Bliss (2002), and from online CoA files (U.S. Department of Agriculture, 2014a).

To keep the product in agreement as much as possible with the NLCD 2001–2011 series, for the year 2002, processing for Agriculture consisted of (a) accepting all Agriculture pixels in the NLCD 2001 (classes 81 and 82) if they did not conflict with the above masking of Water, Conservation, Developed, and Mining/Extraction, and (b) remapping a small number of pixels to and from Agriculture and Low Use, in counties with increases and decreases >1 percent in CoA 2012–2002 Total Cropland (TC). The goal was that the product should agree with the NLCD series, but also show trends indicated by CoA data that may not be given by the NLCD.

The magnitude of all agriculture (Crops + Pasture/Hay) for each region for eras prior to 2002 was based on the regional statistics for CoA TC (in acres) for that year (which includes hay/alfalfa + some elements of pasture). (See Note 15 about adjustments to CoA data.) CoA TC is the statistic that most closely approximates NLCD combined agriculture classes, although they may still represent different quantities. For example, the CoA may indicate TC as 30 percent for a county, but the NLCD may indicate it as 25 or 35 percent, or vice versa (see Note 16). Where the percentage of cropland should increase or decrease for years prior to 2002 in this product was based primarily on CoA county-level changes of TC. The goals were to match trends at multiple scales: (a) Match the processing region's trend direction and general magnitude, (b) match 100 percent of State CoA-indicated trends, and (c) match the trend for at least 95 percent of counties where TC changed by more than 1 percent of the county area, and 90 percent where TC changed at all.

Because of differences between the NLCD and the CoA, a conservative approach was taken to mapping agriculture changes. The NLCD typically shows smaller agriculture changes than would be suggested by the CoA. For example, in the CoA, for any 10-year period, approximately 60 percent of counties had a TC increase or decrease of more than 1 percent of county area, and about 40 percent had more than a 2 percent increase or decrease. For the NLCD 2001–2011, only 12 percent of counties show an Agriculture change of more than 1 percent of county area, and only 3 percent of counties had more than a 2 percent change. The magnitudes of agriculture changes in this product are typically somewhat more than what the NLCD indicates, but less than the CoA.

To incorporate land use changes, similar to the zonal approach for Developed, the landscape was divided into zones corresponding to magnitude and direction of change in TC. For each zone, a relatively larger or smaller proportion of pixels were reclassified to or from agriculture from the previous year and calibrated to match county-level change direction and magnitude. These were then constrained by the overall change indicated by the CoA TC regional statistics. The process was an iterative one, calibrated to result in the goals stated above; that is, it matched direction and magnitude of regional, State, and county-level change, particularly for those counties with > +/- 1 percent TC. For example, for the Appalachia region from 1974 to 1982, according to CoA, 129 counties had a decrease of more than 1 percent land area in TC, and 126 had an increase of more than 1 percent land area in TC. This process correctly matched the trend for all 129 counties with decreases, and 120 of the 126 with increases. (See QA/Validation section below for overall results.)

The exact location of which pixels should be changed within each county was based primarily on (a) mask of “low-probability change” (noted above), and (b) as with the Developed processing, a random number-generated grid combined with information from historical land cover datasets to identify locations that were more or less likely to be agricultural in nature (see Note 17). The HYDE data provided supportive information as to sub-county change locations; 60-m pixels that fell in the larger HYDE pixels with very large changes in agriculture have an increased chance of changing to or from agriculture in our grids.

7. **Agriculture (Level 2 – Crops versus Pasture/Hay):** Once all Agriculture was identified, those pixels were reclassified to Crops (class 43) and Pasture/Hay (class 44). (See Summary section for guidance on whether class 45 may be considered “Agriculture.”) For years prior to 2012, changes in the percentage of crop vs pasture/hay were driven by the CoA regional and county-level change in the following ratio:

$$(CP + HayAlf) / TC, \qquad (1)$$

where CP = Cropland Pasture, HayAlf = Hay-Alfalfa, and TC = Total Cropland (see Note 18).

For 2002, similarly to the Agriculture process above, the class was assigned based on (a) classification from the NLCD 2001 and (b) change in the CoA county-level change in the ratio of equation 1.

For all years, and as with overall Agriculture above, pixels are modified based on graduated zones of increase and decrease in this ratio. The goal of the process was to match the regional trend in increase or decrease in the proportion of Pasture/Hay, with the greatest changes occurring in counties with the largest ratio changes.

As with the process used to distinguish overall Agriculture, distinguishing which specific pixels within the county were likely to represent Crop versus Pasture/Hay was assisted by sub-county information. These were namely (a) a USDA/USGS soil-capability class dataset, which classified land into zones that are more or less likely to be suited to crops, (b) a Digital Elevation Model (DEM)-derived slope grid based on USGS National Elevation Data, which similarly is a controlling factor for location of crops (Baker and Capel, 2011), (c) historical indication of Crop versus Pasture/Hay from the NLCDe 1992, and (d) a random number-generated grid, which allows selection of relatively more or fewer pixels to be affected. These created a probability surface of where Crop versus Pasture/Hay is more likely to be, with the magnitude of change controlled by the magnitude of the (CP+HayAlf)/TC ratio change.

8. **Grazing Potential:** As noted above, based on CoA data, there is very likely to be more grazing in the landscape beyond classes 81 + 82 in the NLCD. To that end, those areas were mapped that have suitable physical conditions (slope and proximity to water) and have agreement from two major datasets (NLCDe 1992 and CDL 2009) indicating grazing and pasture in the last 20 years. The logic for mapping these areas did not change from year to year; any pixel that fulfills the requirements noted above and is not classified as Crop versus Pasture/Hay is placed in this class.

9. **Semi-Developed:** The urban interface classes 31 and 32 are based almost entirely on hden mapping from the SILVIS lab housing density product (Hammer and others, 2004). Class 31 also incorporates a constant set of pixels that represented an “urban core” mask (described in Note 8). Class 32 is based entirely on hden for each era. The logic for mapping class 33 did not change from year to year, but is intended to simply capture pixels where there is very likely a miscellaneous anthropogenic use (primarily recreation or industrial) in any year of the dataset.

10. **Developed (Level 2):** As with the method for Agriculture, once the Level 1 Developed pixels were identified above, they were coded to their Level 2 classes (21–27). This was based primarily on the current-day urban use (method generally described in Falcone and Homer, 2012, and broadly here in appendix 3). At present (version 1 of this product), with minor exceptions, Developed pixels that are coded as a non-Residential class (21–24) in a later year remain in that class in a prior year, and Developed pixels in a Residential class (25–27) likewise remain Residential, although may change Residential class based on that year’s hden. We are aware that “interurban” class changes may occur (for example, a residential area becoming commercial, but also believed to be very

uncommon. (See more discussion on this topic in the Caveats and Assumptions section.) We are investigating methods with which those kinds of interurban class changes may be accurately captured over time for future versions of this product. Those changes that were successfully captured in this product were a result of manual polygon delineations.

After coding the Developed pixels to classes 21–27, a manual check was performed at a scale of approximately 1:100,000 over the entire grid. Some specific land use types are difficult to capture completely correctly using automation (for example, some industrial areas). Where errors were found, correction polygons were digitized, and the process was run again.

11. **Low Use:** Any pixel that was not classified into any of the above classes was classified as class 50.

12. **Timber:** At present, Timber is a special-case land use, maintained as a series of separate grids from the main dataset, and processed after all the above processing was complete. The Timber grids are annual 1999–2012 estimates, based on the 1999–2012 Landfire disturbance grids, as described above. The pool of class 50 pixels from which the Timber grids were drawn were based on the 2002 land use grid for years 1999–2006, and the 2012 land use grid for years 2007–2012, each masked against the appropriate Landfire year.

Quality Assurance

As noted above, as part of the production, we manually examined the entire product by region at a scale of 1:100,000 or finer, looking in particular for major Developed land use features such as industrial sites, water treatment plants, sports facilities, prisons, universities, and so forth, but also included other uses, such as landfills, mining and oil/gas fields, wind farms, and more. The focus was chiefly on current land use; however, spot checks on historical land use were also performed. The grid was compared against current and historical GoogleEarth© imagery (Google, 2013), current and historical land cover datasets, and guided by hundreds of thousands of point locations of features available from the HSIP and EPA datasets. That review process yielded this project's in-house derived database of more than 45,000 land use polygons representing primarily the current era. This supplemented or corrected information from other sources. This was in addition to the nearly 5,000 dam-creation and dam-removal sites examined and the 1,400 conservation area establishment dates manually researched.

In the manual review process, we were particularly attentive to areas of great change as indicated by other sources. From Census county population data, we calculated the percent of population change by county for all U.S. counties (n =3,109) for the period 1970–2010, ranked them, and did an extra manual review of the counties showing the greatest relative population change. The figures in appendix 5 show snapshots of NWALT 1974–2012 grids for the 10 counties with the greatest population density change and 2010 population greater than 100,000 between 1970 and 2010.

As part of the quality assurance process, (a) it was verified that every grid was identically aligned and had the same number of pixels (2.2 billion 60-m pixels), (b) summary statistics by class for the United States and by State were assembled (appendix 6), and (c) it was ensured that the extent of the grid encompassed all of the pixels of the NLCD 2011; that is, all coastal islands and waters shown in the NLCD 2011 are also present in this product.

As noted above, this product is a melding of information from the NLCD, the Census of Agriculture, and other sources. As such, those products are not independent sources for validation; however, it is still informative to compare the level of agreement of this product and the two most major inputs—the NLCD 2001–2011 and the Census of Agriculture information. Those comparisons were performed as part of the quality assurance process and are given below.

Agreement with NLCD 2001–2011

The mean percent developed, percent agriculture, percent crop, and percent Pasture/Hay by county were calculated and compared to the same classes in the NWALT for 2001–2002 and 2011–2012. Agreement for the 3,109 counties is given in table 2. The statistic r^2 refers to the coefficient of determination, and RMSE refers to the Root Mean Squared Error.

The counties with the largest percentage change in Developed and Agriculture, according to the NLCD, are listed here, in comparison to the percentage NWALT change (table 3). Although the biggest changes in Agriculture are almost always decreases, note that one (highlighted) is an increase.

Agreement with Census of Agriculture County-Level Cropland Changes

The net change in TC by county from CoA for the eras 1992–2002, 1982–1992, and 1974–1982 (see Note 15 about 2002–2012) was calculated. A small number of county entities that are cities were excluded because of their very small areas; the total number of counties tested was 3,057. The net change in total agriculture (classes 43 and 44) by county in the NWALT for the same time periods was then calculated. For counties that had a >1 percent increase or decrease in TC between eras, the number of counties in the NWALT that correctly matched the direction of the change was then calculated. The number of counties that agree are given below:

1992–2002: 980 counties lost >1 percent: correctly matched 975 (99.5 percent).

Table 2. County-level comparison of percent of land uses from the NLCD and NWALT datasets (U.S. Geological Survey, 2014c).

[NLCD = National Land Cover Database; NWALT = NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends; r[2], coefficient of determination; chg = change; RMSE = Root Mean Squared Error]

Comparison	r^2, RMSE
Developed, NLCD 2011 to NWALT 2012	0.991, 3.12
Developed, NLCD 2001 to NWALT 2002	0.990, 3.16
NLCD 01–11 chg in Developed to NWALT 02–12 chg in Developed	0.941, 0.20
Agriculture, NLCD 2011 to NWALT 2012	1.000, 1.62
NLCD 01–11 chg in Agriculture to NWALT 02–12 chg in Agriculture	0.956, 0.16
Pasture/Hay, NLCD 2011 to NWALT 2012	0.999, 0.60
Crops, NLCD 2011 to NWALT 2012	0.999, 1.32
Pasture/Hay, NLCD 2001 to NWALT 2002	0.998, 1.00
Crops, NLCD 2001 to NWALT 2002	0.998, 1.17

Table 3. County-level comparison of percent of land use change from the counties that changed the most, according to the NLCD 2001–2011 (U.S. Geological Survey, 2014c).

[%, percent; NLCD = National Land Cover Database; NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends; Dev. = Developed, Ag = Agriculture]

Developed			Agriculture		
County, State	% Dev. chg NLCD 01–11	% Dev. chg NWALT 02–12	County, State	% Ag chg NLCD 01–11	% Ag chg NWALT 02–12
Broomfield, CO	+14.33	+13.69	Broomfield, CO	-10.09	-8.66
Fredericksburg, VA	+11.82	+10.66	Holt, MO	-8.41	-7.45
Gwinnett, GA	+11.35	+10.91	Kendall, IL	-5.86	-5.59
Forsyth, GA	+8.93	+9.69	Will, IL	-5.69	-5.26
Manassas Park, VA	+8.43	+4.82	Kane, IL	-5.21	-4.96
Henry, GA	+8.34	+8.20	Hamilton, IN	-5.15	-5.08
Will, IL	+7.90	+7.60	Freemont, IA	-5.09	-4.65
Clayton, GA	+7.43	+5.04	Harrisonburg, VA	-4.69	-3.45
Harrisonburg, VA	+7.35	+5.40	Johnson, KS	-4.51	-3.99
Harris, TX	+7.21	+7.14	Fort Bend, TX	-4.16	-4.07
Tarrant, TX	+6.86	+7.07	Humphrey, MS	+4.14	+4.44
Fulton, GA	+6.49	+5.96	Walthall, MS	-4.09	-4.57

1992–2002: 995 counties gained >1 percent: correctly matched 936 (94.1 percent).
1982–1992: 1,351 counties lost >1 percent: correctly matched 1,335 (98.8 percent).
1982–1992: 635 counties gained >1 percent: correctly matched 577 (90.7 percent)
1974–1982: 777 counties lost >1 percent: correctly matched 748 (96.3 percent).
1974–1982 962 counties gained >1 percent: correctly matched 921 (95.7 percent).
Overall: Counties that lost >1 percent: 3,058/3,108 correct (98.4 percent).
Counties that gained >1 percent: 2,434/2,593 correct (93.9 percent).

We also verified that every State matched the CoA-indicated trend for those time periods. If the CoA indicates an increase or decrease in TC for a State, this product will likewise increase or decrease in total agriculture for that State area.

Validation

As noted by Theobald (2014), validation of land use datasets presents challenges because of differences in class definitions and interpretation (for example, it is easily possible to interpret "commercial" uses to include very different things), differences in scale, and differences in time periods. This is further complicated in this case because, as we use most nationally available datasets as input in our process, it is difficult to identify independent time-series data sources as validation sets. We did, however, validate this dataset against four different sources of time-series information as briefly described in the following sections. These were as follows: Regional-scale agreement with Midwest States agriculture change indicated by other studies, ecoregion-level agreement with USGS LC Trends data, agreement with MassGIS land use data, and agreement with national-scale ERS major land use values.

Agreement with Midwest Agriculture Changes

Several studies have indicated considerable conversion of natural grasslands to crop production from the late 1990s to the late 2000s in the Upper Midwest. Wright and Wimberly (2013) performed an image-based evaluation of five Midwest States (North Dakota, South Dakota, Nebraska, Minnesota, and Iowa), finding that between 2006 and 2011, approximately 1.3 million acres of natural grasslands and wetlands were converted to corn and soybean production. Similarly, Claasen and others (2011) found that between 1997 and 2007 in nearly the same States (North Dakota, South Dakota, Montana, Minnesota, and Iowa), there was a net increase of 670,000 acres of cropland converted from grasslands.

We compared the above findings to what the NLCD and our product indicated for the five States of the Wright and Wimberly study. The NLCD 2006–2011 showed a net increase of 300,000 acres from natural vegetated categories (52, 71, 90, and 95) to Cropland (82), and the NLCD 2001–2011 showed a net increase of 410,000 acres of those same categories for those five States (and only a minor difference if including net forest to cropland conversion—308,000 and 430,000 acres, respectively, for 2006–2011 and 2001–2011). In other words, the NLCD agrees with the direction and partially matches the magnitude of the two studies.

The NWALT 2002–2012 showed a net increase of 615,000 acres from the Low Use category (50) to the Crops category (43). Although the time periods and categories are slightly different, the NWALT correctly matches the direction and substantially matches the magnitude of the trend shown by both studies, and indeed does so more closely than the NLCD itself.

Agreement with USGS Land Cover Trends Data

The USGS LC Trends data are a measurement of EPA Level III ecoregion (Omernik, 1987) trends derived from sample chips of Landsat data of each ecoregion. These were classified into 10 land cover/use classes, then statistically extended to the entire ecoregion (Sleeter and others, 2013). The trends have measured time stamps of 1973, 1980, 1986, 1992, and 2000 that are similar but not identical to the NWALT's early-year time stamps.

We calculated the NWALT's representation of Developed (classes 21–27) and Agriculture (4–44) for each of the 84 ecoregions and compared that to the LC Trends data for the years 1973–1974, 1992–1992, and 2000–2002. There is generally good agreement between the datasets for those sets of paired years for the 84 ecoregions, and for the overall change (table 4).

Agreement with MassGIS Land Use Data

The MassGIS dataset is one of the more consistent and long-period independent time-series datasets depicting land use available, and covers the State of Massachusetts. It has a consistent mapping of 21 land use categories for three time periods—1971, 1985, and 1999, which were manually derived from high-resolution imagery (more recent years also exist, but are derived with different methods than these). Although the years are not exact matches to this product's years, they are reasonably close to our 1974, 1982, and 2002 datasets.

Table 4. EPA Level III ecoregion-level comparison of percent of land uses and change from the USGS Land Cover Trends project (Omernik, 1987; Sleeter and others, 2013).

[EPA = U.S. Environmental Protection Agency; LC = Land Cover; chg = change; r^2, coefficient of determination; RMSE = Root Mean Squared Error; NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends]

Comparison	r^2, RMSE
Developed, LC Trends 1973 to NWALT 1974	0.863, 1.91
Developed, LC Trends 1992 to NWALT 1992	0.871, 2.13
Developed, LC Trends 2000 to NWALT 2002	0.884, 2.27
LC Trends 1973–2000 chg in Developed to NWALT 1974–2002 chg in Developed	0.742, 0.88
Agriculture, LC Trends 1973 to NWALT 1974	0.945, 6.42
Agriculture, LC Trends 1992 to NWALT 1992	0.946, 5.85
Agriculture, LC Trends 2000 to NWALT 2002	0.953, 5.66
LC Trends 1973–2000 chg in Agriculture to NWALT 1974–2002 chg in Agriculture	0.910, 1.78

We compared these datasets as follows: For all of the USGS Hydrologic Unit Code (HUC)-12 watershed areas that intersected the State of Massachusetts (n = 216), we calculated the mean percent of Water, Agriculture, Mining, Developed Nonresidential, Developed Residential, and Developed Recreation for both the MassGIS and our product for the corresponding time periods (see Note 19). Then, as above, we calculated the r^2 and RMSE of the agreement for the 216 areas (table 5).

Despite the time period and minor class definition differences between the two datasets, there is good agreement for most classes and very good agreement for the Developed classes. Agreement decreases slightly with the earlier eras, with the exception of Mining, which decreases substantially, and Developed Residential, which improves slightly for the earliest era. These results suggest that at the HUC–12 scale for these classes, this product maps most land uses in a very similar fashion to the manually derived State data.

Agreement with Economic Research Service Trends

As noted above, the Economic Research Service has published estimates of major land uses for the United States for 5-year periods since the 1940s. Because there have been method changes in their sources for some land use categories, it is not possible to strictly compare some of them as a time series, and in other cases their categories are a mix of land cover/use (for example, grassland pasture and range) and do not match the categories of this product. However, we do compare our results to ERS results in several cases, where feasible, as follows:

Developed lands. Although this ERS category has changed methods over time, the most recent ERS year that matches this product is 2002; for that year, the ERS measures the amount of land in urban areas for the lower 48 States at 3.13 percent. For that same year, the NWALT measures the amount in Developed lands at 3.27 percent, and measures an additional 2.57 percent as Semi-Developed.

Total Cropland. For years unlikely to be effected by method change in the ERS and CoA, the number of acres of land in this class from ERS, CoA, and our data are compared (table 6) for the lower 48 States:

Recall that the NWALT product is based on the NLCD, whose characterization of agriculture differs slightly from Total Cropland as defined by the CoA and ERS, and which likely has a more conservative approach to measuring agricultural change. Nonetheless, all three products show the same trend: the amount of total cropland increasing back to 1982, then decreasing from 1982 to 1974.

Caveats and Assumptions

- This project did not have detailed information about, nor attempt to map, changes among natural vegetation types (for example, forest becoming wetlands or vice versa) and, therefore, did not maintain those type of detailed natural vegetation breakouts. The focus of the product is on anthropogenic changes.

Table 5. HUC–12 level comparison of agreement between the NWALT and MassGIS classes (State of Massachusetts, 2014). Values in each cell are r^2 (coefficient of determination) and Root Mean Squared Error.

[HUC = Hydrologic Unit Code; NWALT = NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends; Ag = Agriculture; Nonresid. = Nonresidential]

Year pairing	Water	Ag	Mining	Developed Nonresid.	Developed Residential	Developed Recreation
1999–2002	0.785, 1.01	0.760, 0.81	0.525, 0.21	0.976, 0.92	0.935, 3.25	0.781, 0.41
1985–1982	0.671, 1.36	0.720, 1.67	0.287, 0.31	0.943, 0.98	0.937, 2.70	0.750, 0.41
1971–1974	0.671, 1.37	0.710, 1.93	0.188, 0.27	0.929, 1.03	0.941, 1.97	0.760, 0.41

Table 6. National comparison of Economic Research Service, Census of Agriculture, and NWALT-equivalent Total Cropland values (U.S. Department of Agriculture, 2014b, U.S. Department of Agriculture, 2014a).

[Values are in millions of acres and percent change from previous year, stepping back in time. NWALT, U.S. Geological Survey National Water-Quality Assessment Program's Wall-to-Wall Anthropogenic Land Use Trends; ERS = Economic Research Service; CoA = Census of Agriculture]

Year	ERS	CoA	NWALT (classes 43 and 44)
2002	441.3	433.9	459.2
1992	459.7 (+4.17 percent)	435.0 (+0.25 percent)	460.1 (+0.20 percent)
1982	468.9 (+2.00 percent)	444.9 (+2.23 percent)	465.7 (+1.22 percent)
1974	464.7 (-0.90 percent)	439.7 (-1.17 percent)	463.1 (-0.56 percent)

- Urbanization is assumed to be irreversible; a pixel classified as Developed in time t will still be Developed in time *t+1*. (An extremely rare exception in our process is made in the case where an urban pixel may be reclassified as Water if a new reservoir is put in). The irreversibility of urbanization is commonly assumed in other urban studies (for example, Zhang and Guindon, 2005). As a test of this, we examined the MassGIS dataset noted above, and 99 percent+ of pixels that were classified as urban in 1971 were still urban in 1999.

- Urban interclass changes (for example, residential becoming commercial) are assumed to be uncommon, and are not captured in the current version of this product. The belief that they are uncommon is also based on the unpublished work by Zhang and Guindon, as well as our own examination of the MassGIS data. When classified into four broad categories (residential, commercial, industrial, and recreation), 98 percent+ of MassGIS pixels that were urban in 1971 were still the same subtype in 1999. Future versions of this product may be able to capture these minor changes.

- A small number of road segments (part of Developed, Major Transportation; class 21) will be misclassified. Although some changes are captured from known road construction, the primary method for modeling major road changes is by reducing the number of road pixels slightly with each earlier era. This has the effect that over a large area, the percent of pixels that are "major roads" are likely to be approximately correct; however, some specific road segments will be wrong. This likely injects a small amount of overall error, given the small component major roads comprise of the entire grid. That is, class 21 comprises only about one-half of 1 percent of any year's grid, and major road pixels make up only a subcomponent of that, with airports and rail comprising the rest.

- Water changes are limited to those resulting from changes in reservoirs being built or dams being removed. Water bodies <150 acre-feet, except in rare instances, do not change in this product, and are represented as they are in the NLCD 2011.

- This product is based on the NLCD 2011, so errors in that dataset are likely to be carried through the processing. For example, a quarry classified as Agriculture in the NLCD 2011 will still be coded as Agriculture in this product's 2012 grid, even if we have visually noted the error.

- It is not feasible to map changes in oil/gas development alone with these data. Hydrofracturing and other oil/gas development activities have increased dramatically in some parts of the country (U.S. Energy Information Administration, 2012; U.S. Department of Agriculture, 2014e); however, there is not consistent data with which to map surficial effects at a scale useful to this product, particularly going back to early years. Natural gas wellheads are relatively small features often scattered amongst other land cover/use types, and only partially captured even by the NLCD. There are notable difficulties in matching activities that are chiefly subsurface in nature to land use, which is chiefly surficial in nature. To the degree it is captured, oil/gas changes are a partial component of classes 23 (Industrial/Military) and 41 (Mining/Extraction).

- At present, class 42 Timber is being kept as a series of separate grids, as data are not available for all years. Those pixels are classified as 50 in the main product grids from which they are drawn (2002 and 2012).

- Mining changes shown in this data series are likely to have more error and less consistency associated with them than other classes, particularly for the years 1974–1992, as evidenced by results from the MassGIS comparison. As noted above, mining and extraction comprises a very small and geographically scattered portion of the landscape, and mapping consistent mining changes back to the 1970s accurately at a detailed scale is challenging with current data.

Summary

This product provides a U.S. national 60-m mapping of anthropogenic land uses for five time periods: 1974, 1982, 1992, 2002, and 2012. A supplemental national 60-m mapping of Timber is provided annually for the years 1999–2012. The data are based on a modified version of the NLCD 2011 and designed to be broadly in agreement with the NLCD 2001–2011 series and other major sources of land use information back to the 1970s, particularly census-derived housing and agricultural data. A few summary points are provided as user guidance below:

- Because this product recoded a portion of rural Developed pixels in the NLCD 2011 (mainly rural roads) to a non-Developed class, the Developed class of this product will likely more closely represent "urbanization"—in the sense of the built environment of central places—than the NLCD 2011 itself.

- This product further maps changes in suburban and ex-urban residential areas as Semi-Developed lands. In parts of the country, some of the most significant changes in the landscape over the last 40 years have been in these settings.

- Many projects using land cover/use data have an interest in only a single statistic representing Agriculture; that is, they are not examining Level 2 detail.

In this paper and validation, we have considered "Agriculture" to be the sum of classes 43 and 44. Class 45 (Grazing Potential), however, is in essence a "swing" class; depending on their own judgment, users may also want to consider this class to be part of total agriculture as well.

- The overall philosophy of this project was to balance the following four goals: (1) Creating a product that was as consistent as possible with the NLCD 2001–2011 series, (2) agreeing as much as possible with other key data sources, (3) keeping all methods as consistent as possible for all years, and (4) making it as accurate as possible. In some cases, these goals conflict slightly. For example, the data for later years are likely to be more accurate than the earlier years. However, as evidenced by the MassGIS validation results, there appear to be only small differences for the major classes (little change in agreement with the MassGIS data going back in time for Agriculture and Developed). There is some tradeoff in achieving all four of these goals simultaneously.
- The data are designed to be used for zonal comparisons (for example, comparing watersheds through time). The data are best used aggregated to zonal areas of 100 km^2 and coarser. As points of comparison, the median size of HUC–12 watersheds in the United States is 86 km^2; the median size of HUC–10s is 468 km^2. The median size of counties in the conterminous United States is about 1,600 km^2.
- It should further be stressed that these data are one representation of reality. Historical conditions are difficult to capture precisely, and land use in particular is subject to interpretation. It is clear that different organizations and research efforts define land uses in different ways. The goal of this project was to take an NLCD 2011-based version of the land, modify it with the most consistent datasets available, and present a reasonable scenario of how the land was used over the last four decades.

Future Enhancements

The following are under consideration as potential enhancements to future versions of this product:

- Update with NLCD 2016 and CoA 2017 for future years.
- Wetlands changes, if possible.
- More comprehensive capture of interurban class changes, as is possible.
- Enhanced capture of industrial, landfill, and mining.
- Breakout of golf courses and (or) other types of recreational uses as separate classes.
- Enhanced capture of Conservation areas (may be able to get Establishment Dates for many more Protected Areas from CBI).
- Perhaps breakout of Oil/Gas use as a separate class, depending on availability of currently proprietary data.

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Appendixes

Appendix 1. Supplemental Notes to Text

Note 1: The SILVIS lab housing unit product is a consistent mapping of housing unit density (hden) going back to 1940 by decade, at a scale referred to as "partial block groups," a scale intermediate to blocks and block groups. The biggest issue with comparing U.S. Census data as a time series is boundary changes: Boundaries at any Census "geography" (for example, county, tract, block group, or block) may change over time. What effect this has on comparisons between eras is scale dependent. At the national or regional scale, it would have no, or very little, effect; however, it may at a detailed scale. In essence, there is a tradeoff between spatial resolution and consistency over time. Some organizations have, at various geographies, developed algorithms to reallocate data to a common boundary (for example, Radeloff and others, 2005; 1990 hden allocated to 2000 blocks); however, this project did not have access to a product that (a) included the entire period 1970–2010 allocated to a common boundary, and (b) was at least at the block group scale. We examined the various possibilities, and for this project used block group data for 2010 (GeoLytics, 2012), and the partial block group data for the earlier eras (Hammer and others, 2004). These were believed to be the most consistent representation of hden at the finest scale available at the time this project was initiated.

Note 2: In the mid-1970s, the USGS began producing the first nationally consistent land use/land cover (LULC) maps. These were manually created as polygons delineated over high-resolution aerial photography by trained image interpreters (Price and others, 2007); this process took a number of years. The polygon data were referred to as the "LULC" (land use/land cover). In near-parallel development, the USGS developed the Geographic Information Retrieval and Analysis System (GIRAS), a multi-purpose software system for creating digital output from the LULC. In this report, the term GIRAS is used to refer to the digital output—specifically that as assembled by Price and others (2007). The imagery from which the polygons were derived ranged in date from the early 1970s through the mid-1980s; however, the bulk of the product represents the mid-late 1970s.

Note 3: This project used hden breakpoints for several purposes: As a method for breaking the landscape into zones for roads thinning, for distinguishing high- and low-density residential and semi-developed classes, and as assistance in mapping grazing potential and timber, as described above. The breakpoints were all based on our estimate of how hden relates to residential lot sizes. This was estimated at 248 housing units/km^2 (hden) being roughly equivalent to residential areas of one-half-acre lots (taking into account public open space in residential areas, such as roads, small parks, and so forth). An hden of 124 would, therefore, be roughly equivalent to residential areas of 1-acre lots, hden of 62 equivalent to 2-acre lots, hden of 31 equivalent to 4-acre lots, and so forth. Use of the breakpoint 500 relates to one-quarter-acre lots. The percentage of NLCD 2011 Developed pixels that did not represent major roads or non-residential uses kept by hden zone in the road-thinning step were as follows: >62 - 100 percent; 31–62 - 50 percent; 16–31 - 35 percent; 8–16 - 20 percent; 2–8 - 10 percent, and 0–2 - 5 percent.

Note 4: Major roads—Developed pixels in the NLCD 2011 were kept if they intersected a 60-m version of the HSIP 2012 streets layer that is in attribute Func_Class 1–3. These are interstate, arterials, and major collector streets. (See http://www.fhwa.dot.gov/planning/processes/statewide/related/functional_classification/fc02.cfm for more detail about Department of Transportation function classes.)

Note 5: This project employed visual checks and manual digitization of in-house-derived polygons for multiple purposes, as described at several points in the text above. In addition to the other digital datasets already referenced (GIRAS, NLCDe 1992, NLCD 2001–2011, HSIP, and Esri polygons), our two major sources of reference information for this work were imagery from GoogleEarth© (Google, 2013) and online historical Landsat from Esri (Esri, 2014b). GoogleEarth© imagery varies, but is typically high-resolution (1 m or less) color imagery available going back to the early mid-2000s and black-and-white imagery available back to the mid-late 1990s, and occasionally earlier. Online Landsat imagery from Esri (http://www.esri.com/software/landsat-imagery/viewer) allows ready comparison of side-by-side Landsat images from two time periods between 1975 and 2010. Landsat images available have spatial resolution of 30 m (primarily post-1982) or 60 m (pre-1982).

Note 6: The in-house-derived land use polygons began with data originally derived for a previous pilot effort (Falcone and Homer, 2012) and used the sources described in Note 5. These included capture of detailed class information (Anderson Level 2–3) of primarily urban uses to include Institutions (n = 12,985 polygons), Commercial areas (n = 4,221), general Commercial-Industrial (mix of both or it is unclear which one) (n = 5,606), general Industrial (n = 9,068), various categories of Recreation (n = 4,209), Transportation (n = 1,748), and several categories of specific industrial uses, such as Landfills (n = 481) and Junkyards (n = 200), among others. The data represent primarily the current era (2011–2013) and were used to supplement or correct the other data sources.

Note 7: The U.S. Census Bureau provides annual block-level employment data as part of their Longitudinal

Employer-Household Dynamics (LEHD) program (U.S. Department of Commerce, 2014). Census blocks are the finest scale of Census geography. The data summarize the number of individuals whose work place is in each Census block for 20 categories of employment, for example Manufacturing, Retail Trade, Finance and Insurance, and so forth (http://lehd.ces.census.gov/data/lodes/LODES5/OnTheMapDataTechDoc5.0.pdf). For this project, we downloaded the 2010 data, categorized them into two classes—Industrial and Commercial—and joined those to 2010 Census block boundaries (U.S. Department of Commerce, 2012). The categories used for Industrial were CNS02 (Mining, Quarrying, and Oil and Gas Extraction), CNS03 (Utilities), CNS05 (Manufacturing), CNS06 (Wholesale Trade), and CNS08 (Transportation and Warehousing). All other job types were categorized as Commercial. From this, two national block-level Industrial-employment and Commercial-employment grids were made, which were used to help determine predominant land use class if non-Residential.

Note 8: NWALT class 31—To identify pixels that were located in "highly urban areas," both a changing mask of hden >500 and an unchanging urban core area were used. The urban core area consisted of an intersection of a 600-m expansion of the Developed pixels in the low-probability change mask (pixels classified continuously as Developed in the historical datasets), and a mapping of the 1990 Census Urban Areas (U.S. Department of Commerce, 2013), which was a midpoint in the NWALT dataset. All of the pixels in NWALT class 31 are, therefore, likely to have been in proximity to non-residential areas that had a permanent urban function throughout every year of the dataset (for example, an airport), or have become highly urban by virtue of having crossed the 500-hden threshold.

Note 9: NWALT class 41: Mining/Extraction is a minor class and a small part of U.S. surface land use. The last national mapping of mining, class 32 of the NLCD 1992, comprised .0008 of the U.S. surface area (U.S. Geological Survey, 2014c). To capture this, we intersected the NLCD 2011 class 31 ("Barren") pixels against a mask of areas that are likely to have a mining/extraction use. The mask, created for this project, was a combination of five data sources:

a. In-house-derived polygons. As part of the manual review of this project and previous land use efforts (Falcone and Homer, 2012), we digitized approximately 2,200 land use polygons nationally that encompassed mining, quarry, or oil/gas extraction areas.

b. State mining-permitted areas. State-mining permitted area polygons were obtained for several States with extensive mining: Kentucky (Kentucky GeoPortal, 2013), Virginia (Steven Mullins, Virginia Department of Mines, Minerals and Energy, personal communication, September 23, 2012), and West Virginia (West Virginia State GIS Data Clearinghouse, 2012).

c. NLCDe 1992 mining areas. These mining areas were buffered by 120 m.

d. EPA point locations of coal mines, and metal and nonmetal mining (U.S. Environmental Protection Agency, 2014a). These point locations were buffered by 2000 m.

e. USGS 2005 oil/gas polygon areas (U.S. Geological Survey, 2014d). These areas intersected a 2000-m buffer of EPA oil/gas point locations.

Note 10: The Conservation Biology Institute (CBI) Protected Areas Database (PAD) data contains information about the degree of protection and conservation status for land in their database. This project used the "GAP status" field, which is derived from the USGS Gap Analysis Program (GAP) (U.S. Geological Survey, 2014d). Those lands in status 1 are "most protected," and defined as: "An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management" (http://gapanalysis.usgs.gov/blog/iucn-definitions). Lands in other status categories (2 or higher) are not necessarily fully protected from anthropogenic uses, although the uses may be limited. This project, therefore, used only the status 1 lands as strictly "Conservation."

Note 11: If a pixel was reclassified as Water from 2001 to 2011 in the NLCD, was part of a cluster of more than 40 contiguous water pixels, and was within 5 km of a NID 2013 dam, it was accepted as equivalent to our manually derived digitization of reservoir changes. Clusters of 40 or more contiguous Water pixels approximated our threshold of NID storage of 150 acre-feet.

Note 12: The procedure for researching establishment dates was discussed with the CBI, which has an interest in and plans on continuing this work with additional sites in their database. The research for this project was done online. Establishment dates were in some cases simply not available, even after extensive searching (10 percent of total), and in other cases unclear because the area may have been established over multiple years from several purchases or acquisitions. In general, if it was obvious that the largest part of the area was established in a particular year, it was assigned that year. Otherwise, if multiple years were given, it was assigned the earliest year. Information was derived from multiple sources, but several were especially helpful: Wilderness.net (Wilderness Institute, 2014), for example, has an establishment date for all

Wilderness Areas, which comprised 70 percent of the records used. Some States have a comprehensive list for their areas (for example, Missouri and Wisconsin).

Note 13: Consistent digital representations of roads in the United States nationally do not exist before the year 2000. For that reason, this project estimated major road changes for the earlier eras, primarily based on broad statistics of how many fewer major road pixels were likely to have existed in those eras. For 1992, this was assisted by the NLCDe 1992 and the NLCD 1992–2001 Retrofit Change Product, and for 1982 and 1974, from the GIRAS. The estimate used for decadal change is from the American Road and Transportation Builders Association (2014); the U.S. highway capacity grew by 4.6 percent over the period 2000–2012, and 19 percent of that represented major roads. Assuming a similar rate of change for earlier eras gives an estimate of an approximately 0.7 percent increase in new major roads each 10 years (4.6 * 10/12 * 0.19). We recognize that earlier time periods may have had somewhat different rates of change; however, more era-specific data were not readily available.

Note 14: For mining trends prior to 2002, we used the LC Trends (Sleeter and others, 2013) ecoregion percent Mining reallocated to our regions. This gave a general trend and magnitude of mining changes back to 1973 and 1974.

Note 15: The Census of Agriculture (CoA) data are not immune to some method changes through time. For example, from the CoA data collected by the National Agricultural Statistics Service (NASS), there is likely an underrepresentation of some statistics because some farms are not included in the NASS's lists of farms that are sent surveys, or some farm owners do not respond to the survey (Wolfgang, 1997). Before 1997, no adjustments were made for this. From 1997 on, these were statistically adjusted based on known complete surveys ("Area Frame Surveys"). However, because we do not have information on how adjustments might be made for pre-1997 data, we use them "as is," which is a common practice, as far as we know. A further challenge was that a methodological change in the 2007 CoA now causes some cropland pasture to be classified as permanent pasture and range (U.S. Department of Agriculture, 2014c). The amount of Total Cropland (TC) in the 2012 CoA will, therefore, typically be lower than in the 2002 CoA, even if no actual change occurred. Several methods were explored to account for or adjust this, and in these data an adjustment factor is applied as follows:

est-crop2012 = *crop2012* + (*permpast2012* * 0.12),

where *crop2012* = reported 2012 TC in acres, *permpast2012* = area of 2012 Permanent Pasture and Rangeland (which incorporates pasture beyond cropland pasture), and *est-crop2012* is our estimated adjusted 2012 TC. This was based on taking counties that had little or no Agriculture change in the NLCD 2001–2011, and comparing them to statistics for CoA 2002 TC, 2012 TC, and 2012 Permanent Pasture.

Note that this only affects the 2002–2012 transition period. Because there is less certainty about the validation data in this transition period, the 2012–2002 period was not used in comparisons or validation for Agriculture change compared to CoA data (see section on Quality Assurance).

Note 16: The CoA statistic that matches NLCD agriculture the best is TC. For the conterminous United States, the CoA 2002 tabulates TC at 433.9 million acres, while the NLCD 2001 maps 445.2 million acres of agriculture (classes 81 + 82). We compared the 3,109 U.S. counties for those two datasets, and the r^2 is 0.92, with RMSE = 8.2 (percent), mean difference 6.0, and median difference 4.5. That is, generally, the CoA and the NLCD 2001 agree, but 634 counties disagree by 10 percent or more. A few disagree by 30 percent or more (for example, Miner County, S.D.; CoA 2002 = 57 percent; NLCD 2001 = 89 percent). These differences would suggest that changes in the CoA should be used more as a general guide than a strict rule when applying changes to the NLCD.

Note 17: A more effective way to have done this would have been to get a digital representation of actual agricultural fields, which does exist as part of the USDA Common Land Unit (CLU) dataset (U.S. Department of Agriculture, 2014e). Although we attempted to acquire these, they are at present limited to use by USDA personnel. Although they do not exist for historical periods, with them in hand, one might more realistically model which contiguous pixels represented agricultural fields. This is a possible enhancement for future versions of this product.

Note 18: The CoA variables used for these were the following (1974–2002 codes from dataset of Stets and others, 2012):

Cropland Pasture

1974	W74_01049	Cropland used only for pasture or grazing (acres)
1982	C82_05037	Cropland, only pasture or grazing (acres)
1992	C92_060049	Cropland only for pasture or grazing (acres)
2002	C02_08084	Cropland used only for pasture or grazing (acres)
2012	C12_xxxxx	Other pasture and grazing land that could have been used for crops without additional improvements (acres)

Hay-Alfalfa

1974	W74_10032	Harvested acreage, hay crops, dry (acres)
1982	C82_01107	Selected crops harvested, hay - all (acres)
1992	C92_280127	Hay-alfalfa, other tame, small grain, wild, grass silage, green chop, and so forth, harvested (acres)
2002	C02_01117	Selected crops harvested, Forage - land used for all hay and all haylage, grass, silage, and greenchop (acres)
2012	C12_xxxxx	Selected crops harvested, Forage - land used for all hay and all haylage, grass

silage, and greenchop (acres)

Although the names change slightly, they are believed to represent equivalent items, with the exception as noted above with 2012 Cropland Pasture. This variable typically shows a lower quantity than in previous eras, even without actual change, because of CoA method change in 2007. Even though the ratio would somewhat self-adjust in that the denominator TC would also decrease, there is less certainty about strictly comparing the ratio for 2012 and 2002. For that reason, in that transition period, the changes based on the ratio above were multiplied by a weighting factor of 0.5, decreasing the magnitude of CoA-driven crop-pasture transitions. In other words, for 2002–2012, crop-to-pasture or vice versa transitions (which are typically small) are mostly reflective of the NLCD itself.

Note 19: MassGIS classes were aggregated as follows: Water = classes 4, 14, and 20 (Wetlands, Salt Wetland, and Water); Agriculture = classes 1 and 2 (Cropland and Pasture); Mining = class 5 (Mining); Developed Non-Residential = classes 15–19 (Commercial, Industrial, Urban Open, Transportation, and Waste Disposal); Developed Residential = classes 10–13 (Very high, high, medium, and low-density Residential); Developed Recreation = classes 7–9 (Participation Recreation, Spectator Recreation, and Water-based Recreation). NWALT classes were aggregated as follows: Water = classes 11 and 12; Agriculture = classes 43 and 44; Mining/Extraction = class 41; Developed Non-Residential = classes 21–23, Developed Residential = classes 25–27, and Developed Recreation = class 24.

Appendix 2. Product Class Descriptions of the NAWQA Wall-to-Wall Anthropogenic Land Use Trends Dataset (NAWQA, U.S. Geological Survey's National Water-Quality Assessment Program)

[>, greater than; <, less than; hden = housing unit density; GAP = Gap Analysis Program; km = kilometer; km^2, square kilometer; m = meter; NLCD = National Land Cover Dataset]

Class Number/Name	Description
1. Water	
11. Water	Streams, rivers, lakes, ponds, bays, and estuaries.
12. Wetlands	Core wetlands class that does not change between years and is based on agreement of wetlands from three sources/periods: The NLCDe 1992, NLCD 2001, and NLCD 2011.
2. Developed	
21. Major Transportation	Major roads, rail, and airports, along with their associated facilities. Major roads are those equivalent to Department of Transportation function classes 1–3. At the spatial resolution of this dataset, road pixels usually incorporate some adjacent development, and in urban areas, they typically include commercial uses. Minor roads are considered an integral part of other land uses; for example, residential neighborhood roads are a part of the Residential classes.
22. Commercial/Services	Commercial and services. Includes retail stores, shopping centers, office buildings, commercial zones, professional services and organizations, universities, schools, hospitals, churches, prisons, police and fire stations, and so on. May include areas of extensive commercial use where identifiable, such as nurseries or vehicle yards.
23. Industrial/Military	Industrial and military. Includes heavy and light industry, seaports/harbors, manufacturing, mills/factories, utilities, waste/recycling/landfills, energy production, warehousing/distribution, water-management features, major communication facilities, and military bases.
24. Recreation	Recreational areas, golf courses, cemeteries, and parks. Includes spectator recreation venues where identifiable: Sports arenas, racetracks, amusement parks, zoos, and so on.
25. Residential, High Density	Primarily residential development, with hden >500 units/km^2.
26. Residential, Low-Medium Density	Primarily residential development, with hden 16–500 units/km^2.
27. Developed, Other	Low-density developed areas (hden <16) and not classifiable in any other class. Primarily low-density residential, rural roads, or vacant land.
3. Semi-Developed	
31. Urban Interface High	Land not in a Developed or Production land use, but in an urban area (hden >500 or in or near an urban core area). Probable medium-high anthropogenic influence.
32. Urban Interface Low Medium	Land not in a Developed or Production land use, but in a near-urban (suburban, ex-urban) area (hden 16–500 units/km^2). Probable low-medium anthropogenic influence.

Appendix 2. Product Class Descriptions of the NAWQA Wall-to-Wall Anthropogenic Land Use Trends Dataset (NAWQA, U.S. Geological Survey's National Water-Quality Assessment Program)—Continued

[>, greater than; <, less than; hden = housing unit density; GAP = Gap Analysis Program; km = kilometer; km², square kilometer; m = meter; NLCD = National Land Cover Dataset]

Class Number/Name	Description
33. Anthropogenic Other	Miscellaneous non-residential urban uses not captured by the NLCD as Developed and likely to have a persistent presence throughout every year of this dataset (see text). Primarily barren or low-vegetation areas associated with industrial, transportation, or recreation uses (for example, landfills or beaches). Probable low-medium anthropogenic influence related to non-residential activities.
4. Production	
41. Mining/Extraction	Barren areas due to probable surface mining/mineral extraction. Includes mining, quarries, sand and gravel operations, and energy operations.
42. Timber and forest cutting (1999–2012 only)	Forest cutting/clearing not obviously associated with transition to urbanization or agriculture. Has Landfire disturbance code of "clearcut," "thinning," "harvest," "mastication," "other mechanical," or "unknown," has been in a forest class in a historical land cover product, has hden <10, is not on or near a current road, and is outside a city's mask.
43. Crops	Areas used for the production of crops, such as corn, soybeans, wheat, vegetables, or cotton, as well as perennial woody crops such as orchards and vineyards. Includes cultivated crops, row crops, small grains, and fallow fields. Identical definition to NLCD 2011 class 82.
44. Pasture/Hay	Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Identical definition to NLCD 2011 class 81.
45. Grazing Potential	Areas of good grazing potential beyond what is indicated by the NLCD. Information suggests the land could and has been used at least on a seasonal or occasional basis for animal grazing, including woodland pasture. Based on physical parameters and agreement from other land cover datasets: Pixel is within 1 km of water body or within 500 m of a streamline; slope <30 percent; was in a pasture/hay class in **both** the NLCDe 1992 and the Crop Data Layer 2009; hden <124; is not on a military base, protected national park, or similar unlikely grazing area; and would otherwise be in class 50.
5. Low Use	
50. Low Use	No obvious indication of anthropogenic influence, and not in active GAP status 1 conservation (class 60). May have a lower protection status (GAP class 2–3).
6. Very Low Use, Conservation	
60. Very Low Use, Conservation	Areas in GAP status 1 in Protected Areas Database Conservation Biology Institute Edition V2 (for example, National Wildlife Refuges, National Parks, Wilderness Areas, and National Preserves). Does not include lands in the USDA Conservation Reserve Program. Very low human usage.

Appendix 3. Stepwise Main Logic for Classifying Year 2012 to Land Uses

Appendix 3 is available at http://dx.doi.org/10.3133/ds948.

Appendix 4. Stepwise Main Logic for Classifying Years Prior to 2012 to Land Uses

Appendix 4 is available at http://dx.doi.org/10.3133/ds948.

Appendix 5. Figures Showing Counties With the Largest Population Density Changes Between 1970 and 2010, With 2010 Population Greater Than 100,000

Appendix 5 is available at http://dx.doi.org/10.3133/ds948.

Appendix 6a–f. National and State Summary Statistics from the NWALT Dataset

Appendix 6 is available at http://dx.doi.org/10.3133/ds948.

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