COASTAL CHANGE ANALYSIS PROGRAM

How to Use Land Cover Data as an Indicator of Water Quality: Description of Data and Derivatives Used

NOAA Office for Coastal Management
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Introduction

This document provides descriptions of the derived data products that were developed through the Coastal Change Analysis Program (C-CAP) to support watershed-scale assessments of water quality. Though the data themselves do not specifically measure water body impairment, they do highlight the relative effects of different landscape features on water quality, such as increased polluted runoff from impervious surfaces and the mitigating impacts of forests. Specific metrics include the percent cover of impervious surfaces, turf, and forests in watersheds and their riparian areas.

Users of this how-to are encouraged to view each map to gain a better perspective of any given watershed. Comparisons between and among watersheds will help one understand how a target watershed may respond to a large land use change. Users are also encouraged to seek additional information about measured water quality parameters, land use patterns, and landscape composition when assessing the relationships between land cover and water quality. The data and derived information presented in this series of maps provide an initial screening tool from which further investigations can be determined.

Data Used

The primary data sets used in the production of this how-to include land cover, watershed boundaries, and active hydrography features. Sources for each include National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) land cover, as well as the active hydrography features and watershed boundaries derived from the U.S. Geological Survey (USGS) National Hydrography Data (NHD). These sources were selected because of their authoritative nature, national significance, wide-scale availability, and active and ongoing stewardship programs that will ensure that future analyses may be conducted in a consistent manner.

These data are considered moderate resolution products given their granularity and mapping scale, but they stand up to the rigors of regional comparative analyses and are thus relevant at the scales presented.

http://noaa.maps.arcgis.com/home/item.html?id=e7eb6e9decb14c17a2fef4d36fee1714

Coastal Change Analysis Program (C-CAP) Land Cover

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www.coast.noaa.gov/digitalcoast/data/ccapregional
The metrics presented in these maps, including percent impervious cover, turf cover, and forest cover, were derived from the 2010 date of Coastal Change Analysis Program (C-CAP) Regional Land Cover data published by the NOAA Office for Coastal Management. C-CAP land cover data exist for the coastal areas of the United States, are updated every five years, and are incorporated into the National Land Cover Database that is available for the entire United States.

Within the C-CAP classification scheme are four developed classes, three upland forest classes, and two wetland forest classes. There is also an open water class, which for the purposes of estimating the proportion of impervious surfaces, turf, and forest cover in a given area, was ignored due to the assumption that only the land areas contribute runoff to water bodies.

Watershed Boundary Dataset (WBD)

U.S. Geological Survey
www.coast.noaa.gov/digitalcoast/data/nhd
The area examined for each watershed-based analysis was defined by the 12-digit Hydrologic Unit Code (HUC) designated within the Watershed Boundary Dataset published by the USGS Natural Resources Conservation Service. These polygons provided hydrologically relevant areas for landscape analysis. Watershed boundaries provide a useful framework for understanding how receiving waters are affected by runoff from adjacent lands.

Note: Watersheds lacking complete C-CAP coverage were excluded from the analysis.

National Hydrography Dataset (NHD)

U.S. Geological Survey
www.coast.noaa.gov/digitalcoast/data/nhd
Riparian areas are understood to provide important functions for water quality (in addition to their provision of important wildlife habitat). Riparian buffers were processed starting with hydrologically active features represented in the USGS high-resolution National Hydrography Dataset. Specific water bodies, flow lines, and areas were extracted from the database and provided the initialization lines for the buffered areas.

Note: We adopted a 300-foot buffer width for this analysis. This value is at the high end of the range cited in the literature, but it provides a valid analysis unit for the moderate resolution C-CAP data and a conservative framework for habitat analyses (Hruby, 2009; Wenger, 1999).

Data Processing

The original source data were organized and processed using ArcGIS desktop software. All data were projected into Albers Conical Equal Area coordinate systems to ensure accurate area analyses. Several workflows were designed and coded using a combination of Model Builder and Python scripting to facilitate consistent and efficient data processing for states, regions, and national coverages. The principal tool used to compute areas was the Tabulate Area tool, which summarized the various land cover classes within each unique watershed polygon. Further scaling and consolidation was performed using custom field calculations and Python scripting.

Methods

STEP 1: Identify Potential Impacts from Impervious Surfaces

Overview

Impervious surfaces, and other forms of development, reduce the infiltration of water into the ground. They can contribute to higher storm water runoff, greater sediment yields, and increased pollutant loads, all of which can degrade water quality. The map included within this step displays the amount of anthropogenic impervious surfaces measured as a percent of total land area in each watershed. The categories used to portray these values highlight the thresholds for potential anticipated impacts to water quality. Sensitive streams, for instance, can be impacted by as little as 5 to 10 percent impervious surface area, with greater impairments expected when rates exceed 20 to 25 percent.

Analysis

The C-CAP land cover classification scheme includes four classes of development that are defined by differences in the density of constructed or impervious surfaces within each grid cell, or pixel. To accurately compute the amount of impervious surface in any given area, these developed classes were scaled by class-specific impervious surface coefficients. The class definitions and coefficients used for each developed category can be seen as follows.

C-CAP Class Name	IC Coefficient
Developed, High Intensity – contains significant land area that is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.	0.8503
Developed, Medium Intensity – contains areas with a mixture of constructed materials and vegetation and other cover. Constructed materials account for 50 to 79 percent of the total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may all types of land use.	0.5768
Developed, Low Intensity – contains areas with a mixture of constructed materials and substantial amounts of vegetation and other cover. Constructed materials account for 21 to 49 percent of the total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may all types of land use.	0.2929
Developed, Open Space – contains a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of the total cover.	0.0941

The impervious coverage coefficients were calculated by comparing each C-CAP developed category to the NLCD Percent Developed Impervious Surface values, in order to calculate an average impervious surface value for each developed class. These coefficients were then applied to the area of the four developed classes to estimate the amount of impervious area associated with each. These values were then summed to produce a total impervious surface area for each watershed. The total impervious surface area was then normalized by the total land area and converted to a percent for each watershed.

Interpreting the Map

The impervious surface data are represented as the percent impervious cover for each unique watershed. The symbology uses a 7-class graduated color ramp with thresholds set according to Schueler et al (2009) Reformulated Impervious Cover Model. This model recognizes that stream quality is largely a function of watershed impervious cover and thus contrasts stream quality against watershed impervious area. The model acknowledges that there is additional variability beyond impervious cover, some of which can be attributed to other watershed metrics such as forest cover, road density, riparian composition, and land use practices. The wide range of possible stream quality scenarios associated with low impervious cover indicates that these other metrics should be explored when evaluating multiple management practices aimed at improving water quality.

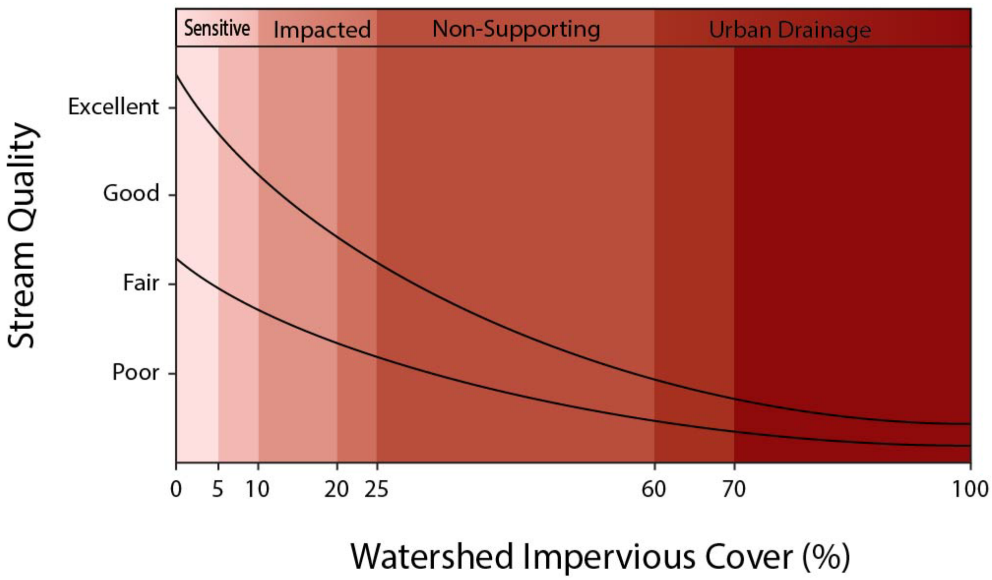

Figure 1. C-CAP impervious cover classification scheme (modified from the Reformulated Impervious Cover Model)

STEP 2: Identify Potential Effects of Forest Cover

Overview

Forest cover provides interception, absorption, and natural pollutant processing for rainfall and surface water. Urban trees serve as an inexpensive storm water practice, lowering water treatment costs. In areas with lower levels of development, forest cover is often the best indicator of watershed health. The map included within this step displays the amount of forest coverage as a percent of total land area in each watershed. Watersheds that are over 65% forested have been found to be protective of a stream's biological community, and a goal of 40% forest cover is recommended in urban areas.

Analysis

The C-CAP land cover classification scheme includes five classes of forests. The areas of these five classes were computed for each watershed and then summed to obtain a total watershed forested area value. The total forested area was normalized by the total land area and converted to a percent value for each watershed. The five forested land cover classes, and their definitions, are included as follows.

C-CAP Class Name
Deciduous Forest – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
Evergreen Forest – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
Mixed Forest – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. *Both coniferous and broad-leaved evergreens are included in this category.*
Palustrine Forested Wetland – includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
Estuarine Forested Wetland – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

It should be noted that the definitions of forest above are based on the presence of tree cover on the ground, and should not be confused with forested land use, which may include other land cover categories associated with timber activities, such as grass and scrub.

Interpreting the Map

The forest cover data are represented as the percentage of forest cover in each watershed. The map symbology uses a five-class graduated color ramp with thresholds set specifically at 40% and 65% following the work by CLEAR (2008). The 40% threshold represents an overall tree canopy goal set by American Forests (2002) to help communities achieve or maintain an array of societal and environmental benefits. The 65% threshold was set following loose interpretations of research performed by Booth et al. (2002) and Goetz et al. (2003), where channel stability and stream health ratings were evaluated according to watershed and riparian forest cover, respectively. The other thresholds at 20% and 80% are used to further differentiate forest cover values within the low and high ends of the range.

Figure 2. C-CAP percent forest cover classification scheme

STEP 3: Examine the Relationship of Forest Canopy to Impervious Area

Overview

Watersheds are composed of groundwater recharge and storm water runoff generation areas. Forests and impervious surfaces represent the two ends of that continuum, with other land covers falling in between. The map included within this step explores the balance between forest cover and impervious area. This “composite” was developed using the dominant thresholds for impervious cover and forest cover. In general, where impervious surfaces are limited in size and scope, forest cover is the primary determinant of water quality. Once impervious surfaces exceed a threshold, they become the determining factor.

Analysis

The total impervious and total forest categories determined in the previous two steps were intersected to explore the relationship between these two factors. The intersection was performed using a series of Python queries operating on the percent impervious and percent forest fields in the analysis database. Watersheds with greater than 25% impervious cover were determined to remain predominantly affected by impervious surfaces rather than forest or other natural cover types. Watersheds with less than 25% impervious cover were broken down into four categories and further analyzed to examine the percent of forest cover present in these areas. Five categories of percent forest cover were identified and incorporated into the matrix analysis. Eleven possible combinations of percent impervious and forest cover were generated and mapped, and are represented using a qualitative color scale.

Interpreting the Map

This map symbolizes watersheds based on the relative amounts of impervious and forest cover. The variation in hue is intended to highlight the primary control on water quality, whether it is high impervious cover or high forest cover. The composite uses an 11-class graduated color ramp to highlight the relative amounts of impervious and forest cover. Red represents high impervious cover and low forest cover, and green represents high forest cover and low impervious cover.

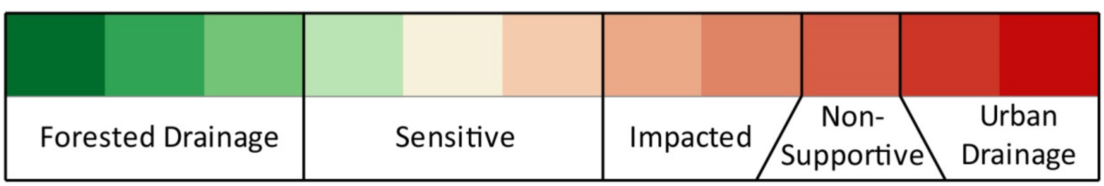

Figure 3. Watershed classification based on relative impervious and forest cover

STEP 4: Identify Whether Developed Grasses Could Be a Factor

Overview

Urban open areas like parks and lawns factor into the development footprint along with buildings and roads. While denser development may pose severe localized problems, lower density development spread across a larger area creates more infrastructure costs and impervious cover per capita. Areas of turf and grass can also exhibit the highest concentrations of pollutants like pesticides and nutrients, but can be pervious and a sink for nutrients when properly managed. The map included within this step displays the difference between the total area of development and the amount of impervious surface within those developed features. The difference in area can be an indicator of the amount of turf and grass within the watershed, and is shown as a percent of total land area.

Analysis

Turf cover was computed by subtracting the impervious area from the total developed area. As was mentioned earlier, the C-CAP developed classes are primarily differentiated by the amount of impervious cover within any given 30 meter by 30 meter cell. For example, a cell that is classified as *developed - medium intensity* is assumed to have 522 square meters of impervious materials within it (30 m x 30 m x 58% = 522 m^2). The remaining 378 square meters of this cell is assumed to be dominated by managed grasses due to the presence of constructed surfaces. While this assumption is not always valid, it provides a useful approach for balancing pervious and impervious covers within developed areas.

Interpreting the Map

This map represents the amount of turf grass present in each watershed as a percent of the whole area. The symbology uses a five-class graduated color ramp using thresholds at 10%, 20%, 35%, and 60%. These thresholds were selected to loosely represent the natural breaks observed in turf cover throughout the conterminous United States at the HUC-12 level.

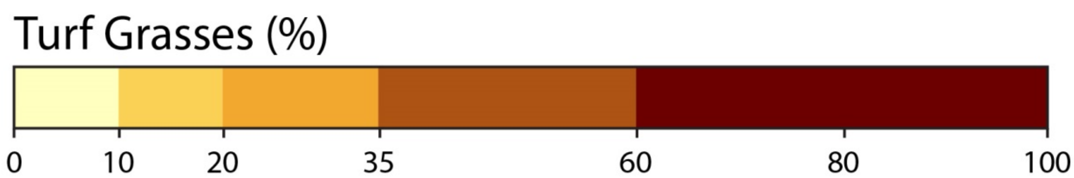

Figure 4. Watershed classification based on turf grass cover

STEP 5: Examine Riparian Buffers

Overview

Riparian buffers can be an important component to stream stability, pollutant removal, and maintaining stream health. Ensuring the integrity of these features, and restoring previous buffers, can have a positive impact on water quality. While a healthy riparian zone cannot totally offset impacts of development, it can be effective when used in combination with other management strategies. The map included within this step displays a simplified version of the C-CAP land cover within riparian buffers. Several of the more detailed forest classes, non-forested wetlands, agricultural classes, and various water classes are collapsed to simplify key areas of interest or concern for users.

Analysis

To generate an accurate representation of riparian areas, certain components of the U.S. Geological Survey (USGS) high-resolution National Hydrography Dataset were used. Specific water bodies, flowlines, and areas that are hydrologically active were extracted from the dataset and tested for network connectivity. A 300-foot buffer was then generated from the extracted network and used to summarize land cover within riparian areas for each HUC-12 watershed. The 300-foot buffer was selected based on expert guidance. Measures of impervious, forest, and agricultural cover were computed following the same methods used in the HUC-12 watershed analyses.

Interpreting the Map

The riparian land cover is presented as a simplified version of the standard C-CAP land cover data, where forest classes, non-forested wetlands, agricultural classes, and various water classes are collapsed into more general categories. This technique is employed to help users visualize the land cover within riparian areas without eliminating the necessary detail provided by each super-class.

STEP 6: Examine Other Potential Water Quality Factors

Overview

Water quality is determined by many physical, chemical, and biological factors. Land cover data represent only one piece of the puzzle. The following potential causes of water quality degradation should also be considered:

- Nonpoint-source pollutants
- Point-source pollutants
- Sources of sediment (clear cuts, slopes, etc.)
- Land use and land use change
- Zoning / future build-out scenarios
- Landscape morphology
- Soil porosity
- Infiltration capacity
- Changing precipitation regimes

Nonpoint-source pollutants are common and pervasive water-quality stressors. These pollutants include sediments, metals, and nutrients. By definition, they can't be attributed to any specific point location, and due to their distributed nature are quite difficult to manage and mitigate. Several tools are available to support investigations of nonpoint-source pollutants.

This step provides users with access to the OpenNSPECT tool. The webpage seen here is the access point for downloading and learning more about it.

OpenNSPECT, the open-source version of the Nonpoint-Source Pollution and Erosion Comparison Tool, is a GIS-based tool that allows you to screen your landscape for potential threats from eroded sediments, metals, and nutrients like nitrogen and phosphorus. Using this tool, you can investigate potential water quality impacts from local development, alternative land uses, and climate change.

Other Resources

Other resources are available to users who would like to produce similar information to that derived within this how-to for areas outside of these coastal areas, or to further customize the analysis performed.

Additional land cover and impervious cover data are available through the Multi-Resolution Land Characteristics (MRLC) Consortium, which maintains the National Land Cover Database (NLCD). These data include both land cover for multiple dates and a Percent Impervious Surface Layer (Xian and others, 2011). This data source is derived from 30-meter Landsat imagery and covers the conterminous United States.

NLCD Land Cover Data
www.mrlc.gov

Impervious Surface Data on the Digital Coast
www.coast.noaa.gov/digitalcoast/data/nlcd-impervious

If users have access to a different source of land cover data and can develop or adapt local impervious surface coefficients, then the Impervious Surface Analysis Tool (ISAT) can be used to compute the percent impervious surface coverage within any given geographic area, such as watersheds, municipalities, and subdivisions. This tool is an extension to ArcGIS and requires Spatial Analyst.

Impervious Surface Analysis Tool
www.coast.noaa.gov/digitalcoast/tools/isat

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