Client Number: 9531299 / CHABAEVA, ANNA
Title: QUALITY ASSURANCE : QA.
Vol./Issue: VOL 8 NO 2
Date: APR 1, 2000
Pages: 91-103
Article Title: * BIRD / GENERATING HIGH QUALITY...
Report Number: ISSN 1052-9411 "FORMAT: SERIAL! OCLC 22415381
Publisher: SAN DIEGO : ACADEMIC PRESS, C1991–
Information Source: OCLC LENDER: *CAI,CAI,BRI,BRI,CAS

INSTRUCTIONS: BILLING NOTES: FEIN 06-6000798 / CISTI: CAID697883 / BRI: 51-9055 / CAS: 5004885 IF DOCUMENT IS DELIVERED VIA ARIEL, PLEASE ’DITHER’ ALL IMAGE PAGES. THANK YOU.

Estimated cost for this 15 page document: $9 document supply fee + $35 copyright = $44
GENERATING HIGH QUALITY IMPERVIOUS COVER DATA

Sandra L. Bird and Linda R. Exum
U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Ecosystems Research Division, Athens, Georgia, USA

Stephen W. Alberty
Computer Sciences Corporation, Athens, Georgia, USA

Nonpoint source pollution (NPS) from urban or suburban areas is rapidly increasing as the population increases in the United States. Research in recent years has consistently shown a strong relationship between the percentage of impervious cover in a drainage basin and the health of the receiving stream. In this paper, we quantify the amount of impervious cover within 56 14-digit hydrologic unit codes (HUCs) in Frederick County, Maryland, USA. This test data set will help in the development of region-wide impervious cover estimation methodologies. The software, sampling and analysis systems were developed to yield accurate and reproducible results. Digital orthophoto quarter quadrangles (DOQQ) from the U.S. Geological Survey were chosen as the basic media for the analysis. Ground features were identified and categorized by human analysts with the help of Geographic Information System (GIS) software and a prototype "cover tool" extension.

Nonpoint source pollution (NPS) or pollution from diffuse sources such as urban or suburban areas and farmlands is now recognized as the primary threat to water quality in the United States (U.S. Environmental Protection Agency, 1994). NPS pollution threats from urban and suburban development are increasing as the U.S. population rises. Along with this increase in development comes an increase in impervious surfaces areas where infiltration of water into the underlying soil is prevented. Roadways and rooftops account for the majority of this impervious area.

Research in recent years has consistently shown a strong relationship between the percentage of impervious cover in a drainage basin and the health of the receiving stream. In a review of research on impervious...
cover, Schueler (1994) concluded that despite a range of different criteria for stream health, use of widely varying methods and a range of geographic conditions, stream degradation consistently occurred at relatively low levels of imperviousness (10–20%). A recent survey of Maryland streams (Boward et al., 1999) found that brook trout (Salvelinus fontinalis), a species very sensitive to water temperature, were not present in any streams where the watershed was greater than 2% impervious cover. The strength of the relationship between stream health and impervious cover is not surprising since impervious cover contributes directly to hydrologic changes that degrade waterways and that channels pollutants directly into waterways preventing processing of pollutants in soils. In addition, impervious cover is significantly warmer in the summer than the vegetated cover which it replaces. Arnold and Gibbons (1996) strongly advocate use of impervious surface coverage as an indicator by planners concerned with water resource protection in urbanizing areas.

The goal of the Office of Research and Development’s (ORD) Regional Vulnerability Assessment (ReVA) Program is to develop and demonstrate an approach to quantifying and communicating regional vulnerabilities so that risk management activities (both restoration and risk reduction) can be targeted and prioritized. The geographic area of interest for this program is EPA’s Region III, which includes five states in the mid-Atlantic region. Impervious cover is proposed as an indicator of aquatic conditions for subwatersheds throughout this region. The utility of impervious cover as an indicator is a function of the ease and accuracy of estimating it. The question, then, is with what degree of accuracy can impervious cover be estimated for subwatershed areas in the region from data available throughout the region, for example, categorized land use or land cover data (Vogelmann, Sohl, and Howard, 1998), block level census data, and roadways. To answer this question, a set of data of known reliability for a spectrum of subwatersheds needed to be collected to evaluate the methods used in the indicator development. This paper discusses an analysis of the options for developing this data set, the development of software tools for data collection, the tests and analyses used to determine the reliability of the data, and the process of achieving quality assurance objectives.

**DEFINING IMPERVIOUS COVER**

Impervious cover when used as an indicator of stream health is typically presented as a percentage of the total land in an area that is covered with impervious materials (%total impervious area). Impervious cover, however, is not a single homogenous quantity. Generally, paved surfaces
and buildings fall unambiguously under the definition of impervious surfaces. Ambiguity can exist even for these categories since there is now a pervious asphalt paving material which allows some infiltration. Other areas such as dirt roads, railroad yards, and construction areas that may not be coated with manmade impervious materials are in many instances so heavily compacted as to be functionally impervious.

Another important distinction concerning impervious cover and its impact on stream health is between connected and disconnected impervious surfaces. Connected impervious surfaces are networked impervious surfaces (parking lots, roads, sidewalks, etc.) that are interconnected and eventually flow directly into stream systems via storm sewers, ditches, and culverts.Disconnected impervious surfaces such as rooftops often deposit runoff onto vegetated pervious areas. The water from these disconnected impervious surfaces flows through the subsurface before reaching stream channel networks, mitigating some of the negative impact on the receiving waters.

**STUDY AND DATA QUALITY OBJECTIVES**

The primary goal of this research is to accurately quantify the amount of impervious cover within 56 14-digit hydrologic unit codes (HUCs, which typically range from 40,000-250,000 acres) in Frederick County, Maryland, USA. This information will serve as a test data set in evaluating regionwide impervious cover estimation methodologies. It was important that the cover type analysis system create a geographic database containing the location of surface features and the feature’s cover type. Several quality assurance requirements were set prior to and during the design of the system. The software, sampling, and analysis systems were required to yield accurate and reproducible results. Additional requirements included the use of high resolution remote sensing data to detect small surface features like sidewalks, driveways, and single lane roads.

In the quality assurance plan developed at the outset of the project, the data quality objective was stated as +/- 10% of the %TIA, that is, a 10% TIA would be measured in the 9-11% TIA range. In retrospect, this was an appropriate objective for areas with 10% or greater TIA. For low impervious areas, however, this objective was not only unreachable, but unnecessarily stringent given the goals for use of the data, for example, data in the 1.6-2.2% TIA (a +/- 20% variability) is functionally indistinguishable. The final data quality objective was restated as +/- 10% of the %TIA for areas with >10% TIA and as +/- 1% for areas with <10% TIA.
An important decision in the initial phase of the study was to decide whether to collect data in only two categories—impervious and pervious cover—or to differentiate between different types of impervious elements. While the multi-category data were not necessary to meet the most basic needs of the study, this data would add significantly to the information data base, support additional research questions, and allow increased flexibility in the use of the data. A decision to collect binary type data was ultimately made on the basis of data quality objectives and resource constraints.

MEDIA AND ANALYSIS SELECTION

Numerous techniques have been used to estimate impervious cover. The most accurate and costly are ground-based surveys. Ground-based methods are prohibitively expensive to use when developing a data base of numerous watersheds, such as this project's indicator evaluation. A variety of remotely sensed data, aerial and satellite based, have been used. Generally, the benefits of reduced cost are offset by reduced accuracy (Sleavin et al., 2000). The resolution of satellite data ranges from 20–30 m² which is insufficient for the classification of small surface features. Aerial photography is generally thought to be one of the most accurate methods of determining impervious cover. Aerial photographs can either be used for a planimetric data base (Kienegger, 1992; Lillesand and Keifer, 1994), a sampling of impervious cover along a line, or the use of dot grids to sample an area (Lee, 1987). Digital orthophoto quarter quadrangles (DOQQ) from the U.S. Geological Survey (USGS) are computer-generated versions of aerial photographs that have been orthorectified so that they represent true map distances. Since DOQQs have a 1 m² resolution and their analysis provides a high level of accuracy in the determination of impervious cover at a subwatershed scale (Zandbergen, Houston, and Schreier, 2000), they were chosen as the basic media for the analysis.

The proportion of area covered by a given type of surface feature can be estimated from digital imagery using spectral or visual feature identification methods. Spectral feature identification uses GIS software to automatically classify features. Visual feature identification involves classifying features manually. Spectral image analysis involves using specialized GIS software to characterize each pixel in an image to determine its spectral reflectance. Pixels with reflectance values within predefined ranges can be grouped together to form feature classes. Spectral analysis software is configured or "trained" to recognize a surface feature based on the spectral characteristics that it commonly exhibits. Image analysis software may allow the user to graphically select
examples of each type of surface feature. The programs then analyze the examples and search the entire image for areas that exhibit the same spectral characteristics.

Spectral analysis works well with multi-spectral color imagery and when the surface features of interest are distinct and can be clearly defined. The DOQQs available for Frederick County during the period of interest were single channel, gray-scale images with a small total variation in spectral characteristics. An example of one of these DOQQs illustrating several pervious and impervious features is shown in Figure 1. Features such as roof tops can have a wide variety of spectral characteristics since roofing materials are available in a broad range of colors. Spectral methods cannot identify the fact that a building or road extends under tree canopy as can be done by a human analyst. While the spectral analysis approach can be very efficient in terms of speed, for this analysis we were not confident that we would be able to achieve our desired level of accuracy using automated methods.

Ground features can be identified and categorized efficiently and accurately by a human analyst with the help of GIS software. Overlaying ancillary point, line, or polygon data on top of a photographic image provides extra information that might be useful in differentiating features. A user looking at a good quality photograph can differentiate features using shape, spatial relationships, and geographic context. For example, a human can reason that a large rectangular feature in a rural area is more likely to be an agricultural field than a parking lot (Figure 1). Even with the help of software tools and ancillary data, visually identifying and categorizing features on aerial photography can be time intensive depending on the size of the area, the density of features, and the speed with which features can be categorized. Visual identification also can be somewhat subjective and can vary from person to person. While the use of visual analysis of DOQQs appeared to be the best option for developing the desired data base, software that allowed for efficient and accurate collection of data along with clear guidelines to maintain consistency between analysts were important considerations for the success of this effort.

The amount of area covered by impervious surface can be measured directly by delineating the extent of each impervious feature found on the DOQQ with a polygon. The relative proportion of impervious cover is determined by dividing the area of all the impervious polygons by the total study area. Because of the spatial distribution, size, and shape of impervious features like roof tops and sidewalks, it is time consuming to draw polygons that accurately delineate each feature. Rather than delineating impervious features for this study, the researchers chose to estimate impervious cover using point sampling techniques.
FIGURE 1 Examples of features in DOQ scenes.

DATA COLLECTION SOFTWARE

The primary software design goal was to develop an efficient, flexible software tool that provided a framework for accurate and efficient cover type analysis. ArcView® GIS from Environmental Systems Research Institute, Inc. (ESRI) was chosen as the development platform because it is the U.S. EPA standard GIS software, was available and familiar to the analysts, and provides an object-oriented programming and development environment called Avenue® (ESRI, 1996). Avenue® scripts were written to add several new functions and controls for characterizing impervious cover to the existing ArcView® user interface. Collectively, these new functions are
DATA COLLECTION SOFTWARE

The primary software design goal was to develop an efficient, flexible software tool that provided a framework for accurate and efficient cover type analysis. ArcView™ GIS from Environmental Systems Research Institute, Inc. (ESRI) was chosen as the development platform because it is the U.S. EPA standard GIS software, was available and familiar to the analysts, and provides an object-oriented programming and development environment called Avenue™ (ESRI, 1996). Avenue™ scripts were written to add several new functions and controls for characterizing impervious cover to the existing ArcView™ user interface. Collectively, these new functions are
referred to as the “Cover Tool.” Cover Tool functions fall into three categories: (1) sample point generation, (2) cover type assignment, and (3) quality assessment.

The sample point generation feature constructs a point coverage in ArcView with a user specified density overlaying a DOQQ. This feature was designed so the analyst could configure the sampling density of a regular sampling grid by choosing the spacing between points in both the vertical and horizontal directions. Alternatively, the user can generate a random coverage containing a specified number of points. A user-configurable sample point generator is one of the original software requirements. It allows an analyst to test a range of grid densities and configurations, and to minimize the amount of time required to analyze impervious cover while assuring that data quality objectives are met. Sample size determination and sampling system design will be discussed below.

Fast and accurate assignment of the cover type was the primary requirement in the design of the data collection software. An integrated point selection and cover type assignment tool was designed to make cover type classification as efficient as possible. An analyst could select one or more similar points and use function keys to rapidly assign a cover type class to the selected sample points. Alternatively, the analyst could click the secondary mouse button to display a context-sensitive pop-up menu and change the cover type classification. Users could choose the classification method that best suited their style, allowing them to work most efficiently. A significant amount of an analyst’s time during on-screen analysis is spent navigating across the coverage. To navigate around an image, a control was designed that allowed seamless panning (i.e., changing the geographic display area). The pan control provided movement across the screen view width in the horizontal, vertical, and diagonal directions thus providing a systematic way to locate and analyze sample points. As an added benefit, the pan control helped the user become oriented on the image and move efficiently across the image in either rows or columns.

To help ensure complete and reliable results, the Cover Tool included reporting and comparison features. The report feature calculates the percentage of pervious, impervious, or unassigned (i.e., not yet sampled) points and lists preliminary or final analysis results. This feature quickly summarizes cover type percentages and helps the analyst determine if any unclassified points remain. The comparison feature analyzes results from two independent analysts, and identifies individual points that are classified differently. After applying the comparison tool, any sample point that is classified as “impervious” by one analyst and “pervious” by
a second analyst will be reclassified by the software as “unassigned.” This allows a third independent analyst to reclassify these conflicting points to obtain the final results for the DOQQ.

**SAMPLING SYSTEM DESIGN**

After completing a prototype version of the Cover Tool, the researchers conducted a series of exercises to test the software and refine the sampling system. The purpose of the exercises was to identify potential sources of error and ensure the validity of the methods.

Two popular schemes for placing sample locations include random and systematic point distribution. A GIS can employ the simple random sampling technique by placing a given number of points at random locations within a specified geographic study area. Properly designed random sampling schemes effectively reduce errors that may arise from regular, repeating features on the landscape and provide defensible results. Under some circumstances they may be logistically difficult and more expensive to implement, however.

Systematic point distribution can be an attractive alternative in cases where random sampling is more difficult. With the systematic technique, a Cartesian grid system with equally spaced points in the x and y dimensions (i.e., in rows and columns) is applied to the study area. When using the systematic approach, it is important that the origin of the grid be positioned randomly (Borgman and Quimby, 1988) to avoid personal bias. Lee (1987) observed no systematic bias using regular versus random grids for sampling impervious cover. During software testing, users found that a systematic sampling system in conjunction with the pan tool provided a very efficient means of locating and classifying sample points. The pan tool could be used to move the photograph to the left and right along rows of sample points, or up and down along columns of sample points. This helped orient users and seemed to increase analysis speed. Randomly and systematically spaced points were analyzed on two separate DOQQs. One DOQQ was located in a rural area (Catoctinse) while the other was more urban (Fredsw). Impervious cover results for random (4.81%) and systematic (4.66%) analyses on the Catoctinse DOQQ were not significantly different, \( \chi^2_{(1,N=4497)} = 0.289, p = 0.60 \), and well within the data quality objectives. Impervious cover results from random points on Fredsw (13.1%), however, were significantly different from those collected from systematic points (14.6%). \( \chi^2_{(1,N=4774)} = 3.94, p < 0.05 \), and slightly exceeded data quality standards.
SAMPLE SIZE

The primary factors used to determine an appropriate sampling density are: (1) the time available for sampling and (2) the quality objectives. The optimal sampling density, therefore, provides maximum precision with minimal effort. Impervious cover was analyzed on two representative DOQQs using a regular grid system. As a test, sample points were positioned 50, 100, 200, and 400 m apart in the x and y dimensions on the Catoctin_se and Fred_sw DOQQs. Analysts then estimated the cover conditions on each DOQQ. The deviation in percent cover from the 50 m estimate was calculated for the two DOQQs and plotted against sample size to aid in determining the optimal sampling density (Figure 2).

Percent impervious cover varied little over the four sampling densities. Even up to a 400 m spacing (~275 points per DOQQ) variation was well within the specified data quality objectives.

ANALYST VARIABILITY

Because visual feature analysis relies on interpretation of aerial photographs, it is somewhat subjective. To quantify variation in cover type results by analyst, the same DOQQ was characterized by six individuals (Figure 3). Each analyst used an identical sampling grid composed of 1,178 points spaced 200 m apart. The results were compared to determine if substantial bias existed between analysts. Some analysts tended to interpret more area as pervious while others tended toward impervious. Estimates of impervious cover for the sample DOQQ ranged

![Sample size and deviation vs. grid spacing.](image)
from 11% to 18%, with an average estimated value of 14%. Only one analyst’s results (Figure 3, Analyst 1) varied significantly from the average, $\chi^2_{(1, N=1176)} = 11.6, p < 0.001$. This range of variability, however, was not acceptable with respect to our stated data quality objectives. The maximum acceptable range would be 12.6% to 15.4%. The subjective judgment required and the resulting analyst-to-analyst variability in the results appears to be the area in the data collection most likely to compromise our data quality standards. In the final development of our sampling protocols, reducing these errors was our primary focus.

**FINAL SAMPLING SCHEME**

A regular sampling grid was used in the final analysis because test analysts found categorization of the random grid much more time consuming and tiring than the regular grid. The difference in results generated by the two sampling schemes was much lower than the analyst to analyst variability, and time and energy were better spent on multiple analyses than on the extra time to analyze the random grid.

Based on the sampling grid size results, a grid spacing of 200 m by 200 m was chosen. This density yielded an average of nearly 800 sample points per 14-digit HUC. This sample size does not appear to compromise the ability to meet the data quality requirements. The number of sample points within the entire Frederick County study area at this resolution totaled 43,816 with approximately three to four hours required per analyst to categorize each DOQQ.
Analytical procedures were developed to simplify cover type decisions and ensure the quality of estimates. Because analysts were identified as a major source of sampling variability, training and validation procedures were designed to promote comparable results. Each analyst received training in photographic interpretation, which included graphic examples of common pervious and impervious features. As a general rule, all analyses were conducted at a scale appropriate for the resolution of the photographs. However, analysts were encouraged to zoom closer (i.e., increase the scale) to help classify hard-to-differentiate points. Analysts were instructed to characterize each point at the absolute center of the point shown on the photograph. For example, analysts were warned against classifying a point as impervious just because it fell “close” to a house.

To ensure the most reliable impervious cover estimates, two independent analysts characterized each of the 63 DOQQs. The DOQQs were randomly assigned to analysts so that no individual analyzed a large contiguous geographic region. A third individual served as a quality assurance checker. This individual imported the results of the first two analysts and compared them on a point-by-point basis. This was accomplished using the Cover Tool’s custom comparison function to

![Figure 4](image_url)

**FIGURE 4** Example of comparison between Analyst 1 and Analyst 2.
Analytical procedures were developed to simplify cover type decisions and ensure the quality of estimates. Because analysts were identified as a major source of sampling variability, training and validation procedures were designed to promote comparable results. Each analyst received training in photographic interpretation, which included graphic examples of common pervious and impervious features.

As a general rule, all analyses were conducted at a scale appropriate for the resolution of the photographs. However, analysts were encouraged to zoom closer (i.e., increase the scale) to help classify hard-to-differentiate points. Analysts were instructed to characterize each point at the absolute center of the point shown on the photograph. For example, analysts were warned against classifying a point as impervious just because it fell “close” to a house.

To ensure the most reliable impervious cover estimates, two independent analysts characterized each of the 63 DOQQs. The DOQQs were randomly assigned to analysts so that no individual analyzed a large contiguous geographic region. A third individual served as a quality assurance checker. This individual imported the results of the first two analysts and compared them on a point-by-point basis. This was accomplished using the Cover Tool’s custom comparison function to

![Cover Tool Screenshot](image)

FIGURE 4 Example of comparison between Analyst 1 and Analyst 2.
identify any classification discrepancies between the two analysts. Figure 4 illustrates the results of the comparison function analysis of the themes that were created by Analyst 1 and Analyst 2. The tool generated a third theme called “Cover Type” that highlighted the discrepancies between the two analysts. In the original categorization, Analyst 1 and Analyst 2 had total impervious cover estimates (16.8% vs. 16.1%) that were close, but when compared on a point-by-point basis, approximately 5.9% of the points were characterized differently by the two analysts. These discrepancies, symbolized by a “X” in the screen view and summarized as unassigned, occurred when one analyst assigned the point as pervious while the other assigned it as impervious. A third quality assurance analyst examined only the points where there was a discrepancy between Analyst 1 and Analyst 2. The final impervious cover for the DOQQ in Figure 3 after the quality analyst review was 15.4%.

SUMMARY AND CONCLUSIONS

The impervious cover from the 63 DOQQs in Frederick County following the final quality analysis ranged from less than 1% to 35%. Only six of the DOQQs were classified as having an impervious cover greater than 10%, and the mean impervious cover for all the DOQQs was 3.7%. After completing the cover type analysis, the percentage of points classified differently by Analyst 1 and Analyst 2 for each of the 63 DOQQs averaged 3.49% (σ = 1.92). The absolute average difference in %TIA between the two analysts for the 63 DOQQs was 1.31%. If we assume that the final results from the quality analyst review is the true value, 33% of the individual analyst results fell outside of the original data quality objectives.

Analyst subjectivity and error appears to be a much greater potential source of error than type or density of the sampling scheme. Follow up discussions among analysts indicated that a majority of the discrepancies between analysts arose from difficulties in determining whether the sampling point was on or off an impervious element such as a house or a road. Occasionally, discrepancies arose from interpretation of what the ground feature was. Very rarely did a discrepancy arise from what might be considered a straightforward recording error.

The software system developed for doing the analysis provided a very efficient framework for recording the impervious cover data. The quality assurance feature of the system allowing rapid identification of conflict points between separate analysts was critical in the development of a data set of the desired quality. Use of two analysts to categorize the cover
with a third quality assurance analyst to resolve analyst conflicts was an effective and efficient system for developing an impervious cover data set.

REFERENCES


