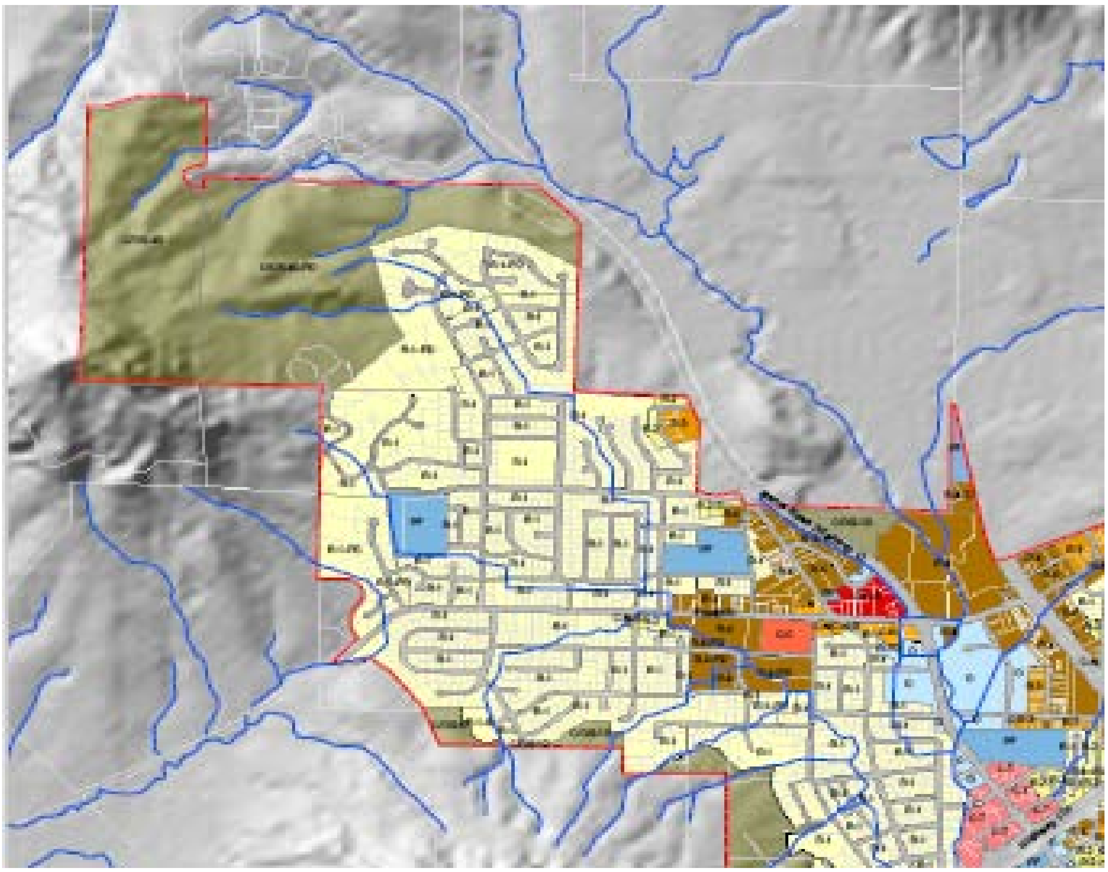
USER'S GUIDE FOR THE CALIFORNIA IMPERVIOUS SURFACE COEFFICIENTS



Ecotoxicology Program
Integrated Risk Assessment Branch
Office of Environmental Health Hazard Assessment

User's Guide for the California Impervious Surface Coefficients

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Table of Contents

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List of Acronyms

AF	acre-feet, measurement of runoff volume
ANOVA	Analysis of Variance
APN	Assessor's Parcel Number
B-IBI	Benthic Index of Biotic Integrity
BMI	benthic macroinvertebrates
BMP	Best Management Plan
Caltrans	CA Department of Transportation
CN	curve number
DCIA	directly connected impervious area
DOQ	digital orthophoto quadrangles
du/ac	dwelling units per acre
EMAP	Environmental Monitoring and Assessment Program
FAR	Floor-Area Ratio
GIS	Geographical Information System
HDR	High Density Residential
HSG	Hydrologic Soil Groups
IA	Impervious Area
IC	Impervious Cover
ICC	Impervious Cover Calculator
ISAT	Impervious Surface Analysis Tool
ISC	Impervious Surface Coefficient
LDR	Low Density Residential
LUC	Land Use Category
LULC	land use/land cover
MDR	Medium Density Residential
NEMO	Non-Point Source Education for Municipal Officials
NLCD	National Land Cover Dataset
NOAA	National Oceanographic and Atmospheric Administration
NPCF	Non-conforming Parcel Correction Factor
NRCS	Natural Resource Conservation Service
OS	Open Space
PQP	Public/Quasi-Public
ROW	right-of-way
SACOG	Sacramento Area Council of Governments

Table of Figures

PREFACE

In rapidly developing regions of California, small streams, including those utilized by anadramous fish such as salmon and steelhead, are increasingly surrounded with new residential developments and shopping malls. Signs of degradation, such as incision and sedimentation, in the aquatic habitat have become abundant.

Understanding the chemical and physical stressors affecting these watersheds will help local governments and others assess which factors contributed to the observed changes. Stormwater engineers, land use planners, and natural resource managers struggle to quantify impervious cover, one of the hallmarks of urbanization.

Office of Environmental Health Hazard Assessment became interested in the estimation of impervious cover (IC) while performing a watershed assessment. OEHHA sought a method with a high degree of accuracy and modest cost that would be easy to implement.

As a first step, a variety of approaches were reviewed:

- LANDSAT imagery was of low resolution (30 meters) so that it could not be reliably used to analyze imperviousness at smaller scales.
- IKONOS Satellite imagery had high resolution (1 meter) but was quite costly to obtain (Goetz et al., 2003).
- The Non-Point Source Education for Municipal Officials (NEMO) Program had been working on the analysis of imperviousness in Connecticut for many years and was continually evolving more refined methods of analysis. At the time OEHHA learned about their work, they had recently published a refinement of a set of coefficients for land cover, including some for urban uses (Prisloe et al., 2002). Yet even these refinements only applied three categories to classify developed areas.

Focusing on an urbanizing watershed, OEHHA worked to develop a set of impervious surface coefficients (ISCs) that reflected the percent of hardened surfaces using the land-use categories described by the Sacramento Area Council of Governments (SACOG). For example, SACOG classifies land uses into approximately 20 commonly used categories. If impervious surface coefficients could be developed for each category, then local governments, planners, stormwater engineers, and natural resource staff could more easily calculate the total impervious area at build-out for a future development or current imperviousness of an urbanized area.

OEHHA developed these statewide ISCs with support from U.S. EPA and the State Water Resources Control Board. This User's Guide describes the methods used to develop the ISCs, and provides applications of the coefficients to a variety of situations.

SECTION I. BACKGROUND

Impervious Surface Coefficient (ISC):

The percent of the area within a given land use category that is made up of hardened surfaces.

$$ISC = \frac{Acres\ hardened\ surface}{Total\ acres}$$

A number of organizations, including the Non-Point Source for Municipal Officials (NEMO) Program and the Center for Watershed Protection, advocate the use of impervious cover for land-use planning purposes. NEMO developed the Impervious Surface Analysis Tool (ISAT) to facilitate these calculations. The Natural Resources Conservation Service (NRCS) developed a set of impervious surface coefficients (ISCs) as a tool for calculating stormwater runoff (NRCS, 1986). NRCS developed these coefficients to estimate the amount of imperviousness associated with seven land use categories. A detailed discussion of this method and curve numbers is provided in Section 5, Stormwater Application. In addition to this dataset, the National Oceanographic and Atmospheric Administration's (NOAA) Coastal Services Center has collaborated with others to develop the National Land Cover Dataset, which includes impervious cover datasets developed from 30 meter Landsat data. These data are available via NOAA's Digital Coast website.

The NRCS and NOAA datasets possess some limitations. For instance, Landsat data has a relatively low level of resolution that does not provide sufficient accuracy for analysis of sub-watershed and local planning areas. A limitation of the NRCS values is the modest number of CNs for urban land uses, in contrast with the large number of values for agricultural uses. Most California cities have identified 15 – 20 land use categories in their general plans; some communities have many more. Today, the range of densities for residential land uses varies from 1 dwelling unit per acre to 15-plus units/acre. This higher value likely will increase as communities emphasize higher-density development. The limited number and scope of NRCS values introduced uncertainty into the analysis of impervious cover, especially for smaller watersheds on which we and many others were conducting assessments.

For all of the above reasons, the Office of Environmental Health Hazard Assessment has developed a set of ISCs that focus on urban land uses that are commonly used throughout California.

SECTION II. HOW THE IMPERVIOUS SURFACE COEFFICIENTS WERE DEVELOPED

OEHHA first selected three cities to represent California's diverse land use classifications: the Sacramento region, Irvine, and Santa Cruz.[1] In selecting these cities, OEHHA employed a few key criteria, including geographical location, the availability of high-resolution aerial photography and digitized land use maps, and the willingness of the planning departments within each municipality to assist us with the project. The three cities selected are described below:

- **Sacramento**, a fast-growing city in the Central Valley where greenfield conversions occurred at a rapid pace during the housing boom. High percentages of Sacramento's development are suburban (not high-density). Data from the western portion of Placer county (part of the Sacramento metropolitan region) include portions of the Sierra foothills, providing additional diversity to the dataset. Since the original data from the Sacramento region was collected from sites from northern Sacramento and western Placer counties, OEHHA expanded the geographical range to include sites south of the American River.

- **Irvine**, a southern California city that has been built out, containing primarily densely populated urban development, yet retaining some land zoned as rural/agricultural preserves.

- **Santa Cruz**, a mid-sized, coastal community with a few land uses unique to coastal areas of the state.

Before scaling up the project, we reviewed a variety of methods for impervious surface analysis. For the original project, we used an interactive approach using a geographical information system (GIS). It involved digitizing impervious areas off of high-resolution aerial photographs and land use data layers. This and other methods were reviewed and determined to have the benefits of high accuracy and precision, relatively modest cost, and the availability of the data layers. (See Summary Table at the end of this chapter, Sturman 2007). Consequently, OEHHA decided to continue using the interactive GIS method to develop the California coefficients.

The following section describes the methods used to derive the ISCs.

***Step 1**: Assemble the necessary GIS layers.*

The data layers used included:

- Current high resolution digital aerial orthophotographs of each city. The resolution of the photographs ranged from 6 inches to 2-feet per pixel.

- Land use data layer. Land uses are typically defined in the general plans. Local jurisdictions may have multiple types of layers that contain land use information. This data layer was obtained directly from the cities of Irvine and Santa Cruz. For the Sacramento

[1] We considered Fresno as an example of a southern Central Valley urban area; however, due to budgetary constraints and the lack of availability of data, this city was dropped from the group.

region, data were obtained from the Sacramento Area Council of Governments (SACOG). This data layer was developed from current and planned uses of land and derived from existing zoning as well as General and Specific Plans.

Step 2*: Test digitizing methods.*

Three GIS analysts took part in the data collection. To standardize the interpretation of the aerial photographs the analyst digitized impervious cover associated with residential and commercial land uses. After reviewing the work to identify potential discrepancies, the analysts adopted a set of common guidelines for interpretation of the aerial photography and digitization, in order to minimize 'between-analyst' variability. Some of the guidelines adopted include:

a) Gravel driveways in rural areas were treated as impervious areas;

b) Detention ponds in commercial areas, especially industrial sites, were assumed to be non-porous and therefore digitized as impervious areas,

c) Roadways within apartment complexes used for internal circulation or parking were digitized as part of the impervious cover of high density residential uses and not evaluated as typical roads (e.g., local or arterial roads); and

d) When tree canopy blocked the view of the land surface below, the line and angles of exposed impervious cover were followed, based on the best interpretation and general familiarity with the land use. For example, cars parked under trees in a paved lot were assumed to be parked on pavement.

Step 3*: Select ample sites and digitze impervious cover on a preliminary set of sites.*

OEHHA adopted a stratified random sample design similar to the one used by the US EPA's Environmental Monitoring and Assessment Program (EMAP). Using Hawth's tool in ArcGIS, 100 randomly selected sites for each land use category (LUC) in each city were identified, a sample point was placed on the land use map, and a unique identifier was assigned to each point (Figure 1). To select the area to be examined, analysts drew a square of 40,000 square meters (about 9 acres) around the sample point (Figure 2). All occurrences of the same LUC in which the sample point fell were analyzed for impervious cover. For example, if the sample point was located in the low density residential LUC, impervious areas for all low density residential LUCs within the square outlined digitally. If the selected point fell on a LUC that did not correspond to the current land use, as evidenced by inspection of the aerial photograph, OEHHA disregarded this sample site. This circumstance commonly occurred when the general plan designated an

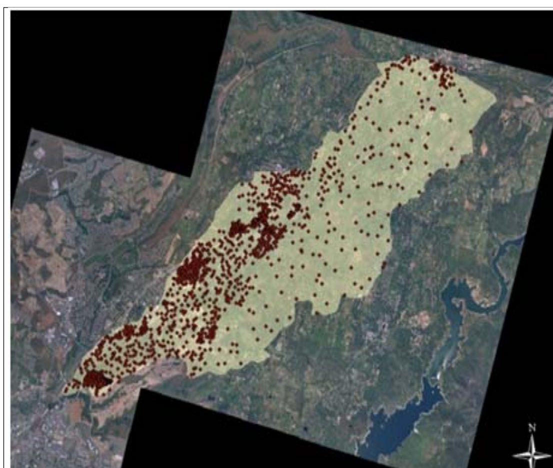

Figure 1. Sampling Points. 100 points were randomly generated for each LUC in each city. Then impervious areas within each LUC were digitized in the order identified by the random selection of sites.

area for development, but the current land use, as interpreted from the aerial photograph, remained in a 'less developed' condition. Applying this principle, land currently used as rangeland but zoned for future commercial development would be disregarded.

Figure 2. **Analysis Box.** An example of a randomly generated sample point around which a 40,000 sq. meter box, approximately 9 acres, was constructed. All impervious areas within the LUC on which the point was found and within the box were digitized.

Step 4: *Determine sample size required for each LUC to obtain the desired level of accuracy and precision and collect data.*

To determine the minimum number of sites for analysis to obtain 90 percent confidence with a 10 percent level of precision, we initially collected data from about 10 sites for each land use category in each city. Sample sizes were determined using a standard sample size calculation for proportions (Daniel 1978):

$$\mathbf{n = (pq)/(d^2/z^2)}$$

where,
p = decimal percent imperviousness,
q = decimal percent perviousness,
d = level of precision, in this case 10 percent,
z = value from the z table associated with 90 percent confidence

Based on the results of this analysis, additional samples from each LUC for each city were collected. Sample sizes for various land use categories ranged from 10 to more than 40 sites/LUC/city, depending on the variability. In general, there was less variability in imperviousness among commercial and retail sites than residential sites, with the result that residential sample sizes were typically larger than commercial sample sizes. Sufficient sites were then analyzed to achieve the desired level of accuracy and precision.

Step 5: *Statistically analyze the results and calculate impervious surface coefficients for residential and non-residential LUCs.*

We analyzed the data based on three major land-use categories: 1) commercial and other non-residential uses, 2) residential land uses, and 3) roads (See Step 6 for further discussion of roads).

- The goal of the non-residential LUC analysis was to identify a set of coefficients that represented land uses common to the three cities. Non-residential LUCs were grouped into three major categories; retail, office, and industrial, each of which contained two classifications. There were five additional non-residential categories of a singular nature: public/quasi-public, mixed use, open space, coastal development, and agriculture. Frequently, different communities used different names to describe essentially the same land-use category. We reviewed the descriptions in the general plans to identify equivalent uses regardless of name. Analysis of variance was used to determine if the mean ISCs for any single commercial LUC differed. Where differences were identified, Tukey's Honestly Significant Difference test was used to differentiate between cities. All data analysis was performed using Statistica (Statsoft, Tulsa, OK). Ten basic categories of commercial land use were identified, with an 11th category, coastal development, specifically found only in Santa Cruz. The 10 non-residential LUCs were: Retail, Retail/Office, Office Park, Urban Office, Light Industry, Heavy Industry, Public/Quasi Public, Mixed Use, Open Space, and Agriculture.

- Residential land uses were analyzed by density or dwelling units per acre (du/ac). After exploring a number of different methods for analyzing imperviousness of residential land uses, OEHHA determined that a regression approach offered the greatest flexibility for the user. Over 330 sites from residential LUCs were analyzed by regressing density against the percentage of impervious cover. These data were fitted to linear, logarithmic, and exponential relationships, using the Box-Cox transformation to optimize the fit. While the Box-Cox linear regression equation minimized residuals for most of the data, it did not adequately reflect percent impervious cover for high density housing due to the small number of sample sites in this category. We believe that a logarithmic relationship most accurately represents the percent IC for a range of housing densities between 1 – 50 units/acre. Details of the basis for this approach are discussed in Section III.

Step 6: *Determine a set of impervious surface coefficients for roads.*

Data was collected from the three study cities for local, collector, and arterial roads as well as highways. The right-of-ways (ROW) polygons were extracted from the local jurisdiction's centerline shapefiles. The extraction was accomplished by creating a new polygon data layer by subtracting the total area of all LUC polygons from the total areal extent of the analysis; the remaining area representing the ROW. Using this geometry, sampling sites (n=356) were identified using the same process used for the residential and commercial land uses. All impervious surfaces were digitized and the percent IC associated with each road type for each city was calculated. Private roads such as those within apartment complexes were not included in the analysis of roads but as part of the impervious area of the land use category.

Due to limited resources, most of the road sample sites (total sample size = 265) were drawn from the Sacramento region; 30 sites were analyzed in Irvine and 61 in Santa Cruz. The disproportionate amount of data collected from Sacramento meant that the level of accuracy and precision of the impervious estimates was greater for this city. To reflect this, weighted averages were used in the final calculation of percent IC for urban/suburban roads, rural roads, and highways.

OEHHA determined the proportion of local, collector, and arterial roads in the Sacramento region and used this ratio for weighting the ISC values. To calculate the urban/suburban roads ISC, we took the weighted average of the ISC for the 3 road types from each city. We calculated the overall average for suburban/urban roads, weighting the data to reflect the higher level of confidence in the Sacramento values due to the larger sample size than the other two communities. The procedure for rural roads was similar. Rural roads data were only available from Sacramento and Santa Cruz, since there are no rural areas in Irvine. Highway data were derived only from the Sacramento region. Because highways are built with standard specifications under the auspices of a state agency, Caltrans, these should be relatively uniform throughout the state.

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Summary of Methods of Impervious Cover (IC) Analysis Reviewed for this Project

Name of Method	Method Category	Summary	Limitations
Contra Costa County	Aerial photogrammetry	Used aerial photography to estimate the amount of IC for a given lot size in each zoning district type. Measurements were not meant to give a precise measure of % IC, but to create a tiered scale for flooding fees on the basis of zoning district and lot size.	Lack of documentation, use of older technology. Analysis by NEMO found that IC estimation based on lot size was much less accurate than techniques relying on more modern land use/land cover (LULC) analysis
Maine Combo	Aerial photogrammetry and digital data	Users digitized polygons across the state, estimated the number of buildings within an acre, and used a graduate student's formula to determine the % IC for residential areas or for commercial-industrial-transport areas. A corrective multiplier was used to adjust the student's formula closer to the results of detailed watershed studies previously performed.	There is little documentation related to this method, especially as to how the formulas and algorithms were determined. Assumptions such as buildings per acre and the corrective multiplier would be specific to the region. Estimations were performed on only two land cover categories
Native Communities Development Corporation	Satellite remote sensing	Commercial vendors of satellite imagery can produce highly accurate measurements of IC over areas of great size, but measurements are for current construction only and cannot be repeated (without purchasing additional services). This method would provide accurate IC measurements but would require further analysis, with LULC layers for example, to create a useful tool.	Because of the high cost of purchasing satellite imagery, this method is most cost-effective for analysis of very large areas, such as statewide. However, some suggest digital orthophoto quadrangles (DOQs) can be used. Studies as recent as 2003 (Herold et al.) found several issues with this method, including haze, shadow, and clouds affecting the multispectral analysis; inaccuracies due to canopy cover; difficulty in attaining quality images after repeated attempts; and time/knowledge required to train the software before analysis.

Name of Method	Method Category	Summary	Limitations
Frederick County Point Sampling	Aerial photogrammetry	This project laid a grid of sampling points over DOQs, and users visually identified whether the point rested on an IC or a pervious surface. The %IC could then be determined for a given area. Custom tools had been created so the analysis could be done quickly and accurately	Different density point sampling grids returned similar %IC measurements, random sampling points are preferred over systematic sampling (though systematic is easier to conduct), and the greatest variability occurred between analysts' visual judgment of surface types. This method could be used for areas that do not have GIS data. A NEMO study (Chabaeva et al. 2004) found this technique to be less accurate than others.
Wayne County	Ground survey, existing maps, aerial photogrammetry	Aerial photography was used to digitize and directly measure the impervious area (IA) from a sampling of photos in each watershed. These results were then extrapolated to the total area of the watersheds. Directly Connected IA (DCIA) was based on 300 field surveys.	While this method can estimate the DCIA in an area, it would be costly and time consuming to perform the field surveys.
Utah State University Extension	Existing maps and digital data	This project was typical of others using digitizing over LULC and aerials to calculate IC across a given area.	Factors contributing to low accuracy include digitizing areas of development rather than individual buildings and the use of ISC that were not designed specifically for Utah. Detailed documentation is lacking for this method.
Direct Digitizing	Imagery and existing maps or digital data	This method refers to hand digitizing all IC features in a watershed or other boundary.	Because of the time required, this method is best suited for small study areas or areas with little development, as was the case in the Cook Inlet Keeper project. Accuracy is very high because all features are captured, but depends on the resolution of the imagery used or on the quality of the planimetric data. Because of the increased availability of planimetric data, hand digitizing might be unnecessary.

Name of Method	Method Category	Summary	Limitations
Parcel Size (NEMO)	Existing maps or digital data	To derive a set of ISCs, the ArcMap Union tool was used to combine 1990 Census tracts, LULC, and impervious features for nine Connecticut towns. Impervious surface coefficients could then be determined as a calculation of the total area of IC within each land cover within each tract. Instead of relying on the towns' definitions of high, medium, and low density (for a residential area, for example), a scale was used to designate tracts as high, medium, and low density. Modifications were made to the method to accommodate areas with high IC but low population density, such as commercial and industrial.	While the report concluded that the results were accurate, it did note that error might occur when analyzing small geographic areas (less than several hundred acres). Correlating population density data while developing the coefficients might increase the accuracy as other methods have used LULC and planimetric data only. Having the population density data also allowed the researchers to experiment with the Impervious Surface Analysis Tool (ISAT), produced by NEMO and NOAA.
UConn Regression Model	Existing maps and digital data	This method used the ArcMap Union tool to combine planimetric and LULC data from several Connecticut and surrounding municipalities to develop a set of ISCs and a regression model (adding in population density) to estimate IC using a national dataset such as the NLCD. This model could then be applied to Connecticut communities having poor planimetric data but are covered by the national dataset.	While this method provides coefficients for future use, they are based on Census data and NLCD, which have up to 10-year gaps before they are updated. Using population density data might provide better results as an addition to other methods relying on planimetric and LULC data only. Relying on direct measurements of quality planimetric data (assuming it is available) is likely preferred over this method.
Population Density (NEMO)	Existing maps or digital data	Developed a set of IC coefficients by using the ArcMap Union tool to combine 1990 Census tracts, LULC, and impervious features for nine Connecticut towns. ISC could then be determined as a calculation of the total area of IC within each land cover within each tract. Instead of relying on the towns' definitions of high, medium, and low density (for a residential area, for example), a scale was used to designate high, medium, and low density tracts. Modifications to the method were applied to accommodate areas with high IC but low population density, such as commercial and industrial areas.	While the report concluded that the results were accurate (and more accurate than the Parcel Size method by NEMO), it did note that error might occur when analyzing small geographic areas (less than several hundred acres). Correlating population density data while developing the coefficients might increase the accuracy as other methods have used LULC and planimetric data only. Having the population density data also allowed the researchers to experiment with the Impervious Surface Analysis Tool (ISAT), produced by NEMO and NOAA.

SECTION III. RESULTS: A SET OF IMPERVIOUS SURFACE COEFFICIENTS FOR CALIFORNIA

A. Non-Residential Land Uses

The results of the analysis yielded a set of 11 ISCs, shown in Table 1, followed by a brief description of each category. Table 1 (below) identifies the non-residential categories and their corresponding mean, 95% confidence interval, and sample size (n).

1. Retail

Table 1. Non-Residential ISCs

Non-Residential ISCs	
Land Use	**California ISC**
Retail	**.86** (83-88; n=83)
Retail/Office	**.80** (76-84; n=40)
Coastal Development	**.23** (16-31; n=10)
Office Park	**.69** (65-73; n=51)
Urban Office	**.85** (82-89; n= 51)
Light Industry	**.81** (77-85; n=54)
Heavy Industry	**.91** (86-96; n=24)
Public/Quasi-Public	**.44** (37-51; n=40)
Mixed Use	**.80** (76-85; n=50)
Open Space	**.02** (1.3-3.1; n=50)
Agriculture	**.04** (2.7-5.3; n=25)

Commercial land uses refers to retail shopping areas such as downtown commercial areas, malls, and big-box outlets, where office uses are only a minor or non-existent component. A total of 123 sites were analyzed in this land use category in the three cities. The ISC values for the 4 commercial categories ranged from 75 – 93 percent impervious. This data fell into two major categories: those retail uses in which office uses were trivial or non-existent and those uses with greater than 5-10 percent office. The former tended to have a higher percent impervious cover uses compared to those with greater total area devoted to office uses. OEHHA divided the two types of commercial land uses into two categories: 1) **Retail** – characterized by neighborhood, community or regional malls or shopping areas in which office uses are less than 5 percent of the total area, and 2) **Retail/office**, where office comprises greater than 5 percent. **The ISCs are 86 percent and 80 percent respectively.**

Two issues of interest should be kept in mind when performing analysis of the commercial LUC.

- Sacramento's retail land had lower levels of impervious cover (IC) than either Irvine or Santa Cruz. We suspect this is due to the fact that much retail development in Sacramento occurs in greenfields where space is not an issue as it is in highly urbanized Irvine or in Santa Cruz, where space is limited by the coastline. As a consequence, we suggest using the Retail/Office ISC for all development that occurs in greenfields, regardless of the amount of office space.

- No differences in impervious cover existed between shopping centers with neighborhood or regional scopes. Therefore, although most cities have a few categories of commercial land uses (e.g. neighborhood, community, and regional retail); they basically contain the same amount of impervious cover. Inclusion of office space in the commercial development had a greater influence on IC percentages than the scale of the commercial development.

2. Office

The Office LUC refers to urban and suburban office buildings. Based on the results of ANOVA, followed by Tukey's test (n=104), suburban office parks had a lower amount of imperviousness than urban offices. Suburban offices have considerably more green space and landscaping surrounding them than offices found in a more urban setting. As a consequence, we identified two ISCs for office uses: *Urban Office* (sometimes called high intensity office); and *Office Park* (commonly found in outlying areas and suburbs), which contain **85** and **69 percent** impervious cover respectively.

3. Industrial

OEHHA identified two types of industrial LUCs by analyzing 78 sites with individual LUC names such as Light Industry, Urban Industry, and Heavy Industry. The statistical analysis showed that these sites could be separated into two categories: Heavy Industry composed of sites with little greenspace, and Light or General Industry, composed of some warehouses and manufacturing campuses (information technology companies serve as a good example) that contain more landscaping. The ISCs are **91** and **81** percent respectively.

4. Coastal Development

The LUC Coastal Development is unique to Santa Cruz and other coastal communities in California. This LUC describes businesses along wharfs and marinas such as restaurants and retail shops. The sites analyzed also included water within their footprints. Since Santa Cruz was the only coastal community analyzed and since the sample size was small (n=10), the ISC of **23 percent** should be interpreted as provisional.

5. Mixed Use

Mixed Use refers to a variety of urban land uses that include a mix of medium to high density residential development, commercial, public/institutional uses (e.g., child care centers, dance studios), and offices. Thirty-six sites were analyzed in Irvine and Sacramento in this category. At the time our analysis was performed, Santa Cruz did not identify a separate Mixed Use category. Instead, this category was folded into the Community Commercial designation. Since that time, Santa Cruz has updated their general plan and has a separate Mixed Use category. The ISC for the Mixed Use LUC of **80 percent** is based on analysis of sites in Sacramento and Irvine.

6. Public/Quasi-Public

Public/Quasi-Public (PQP) represents a unique land use category, because the designation is based on ownership, not the type of use. As such, it had the greatest variability of any of the LUCs that were analyzed. Analysis was drawn from data (n=40) from Santa Cruz and Sacramento because there is no PQP LUC in Irvine. The mean percent IC in Sacramento was 37 percent while in Santa Cruz, it was 64 percent. The California ISC is **44 percent**, with a coefficient of variation of 50% (CV = standard deviation/mean). There is no single recommended ISC we can suggest due to the large difference we observed. Users of the coefficients should consider characterizing the nature of the lands within the PQP category in their community and select from one of these three values (37, 64, or 44 percent).

OEHHA visually inspected all PQP sites in Sacramento and found they included a number of schools, one junior college, a cemetery, a building associated with an airport, and public utility buildings. If these types of buildings characterize the PQP in your community, perhaps the Sacramento PQP ISC of 37 percent might be best. If local land uses are more intensive, then a higher value might be more appropriate. Since this category does not account for large amounts of land, errors associated with an inappropriate ISC will likely not affect the overall impervious cover analysis.

7. Open Space and Agriculture

The open space LUC comprises parks, nature preserves, and forested areas. Fifty sites were analyzed with the average **ISC of 2 percent.** An agricultural LUC was found in all three cities. Even in the middle of the Los Angeles Metropolitan Area, Irvine's General Plan provides for protection of a small agricultural reserve area within the city limits. The California **ISC for agriculture is 4 percent.**

B. Residential Impervious Surface Coefficients

Residential land uses vary from city to city, but are usually defined as a given density range, reported as dwelling units per acre (du/acre). It is common to find low, medium-low, medium, medium-high, and high residential LUCs in each city plan. These residential LUCs are somewhat subjective depending on what an individual city defines as low or high density. For example, there is a range of definitions for the "medium density" LUC. Sacramento defines "medium density" as a residential development with a density of 8-12 du/acre; Irvine defines it as 5-10 du/acre; and Santa Cruz defines it as 20-30 du/acre. The difficulties of using narrative classifications for various residential ISC became apparent quickly. To address this source of variability, we based the California residential ISCs on a regression equation that relates the density (dwelling units/acre) and impervious cover. This equation can be used to determine the ISC that is appropriate for any density of residential development, from rural residential to densities as high as 50 du/acre. The regression equation that best describes the relationship between residential density and impervious cover is shown in Figure 3.

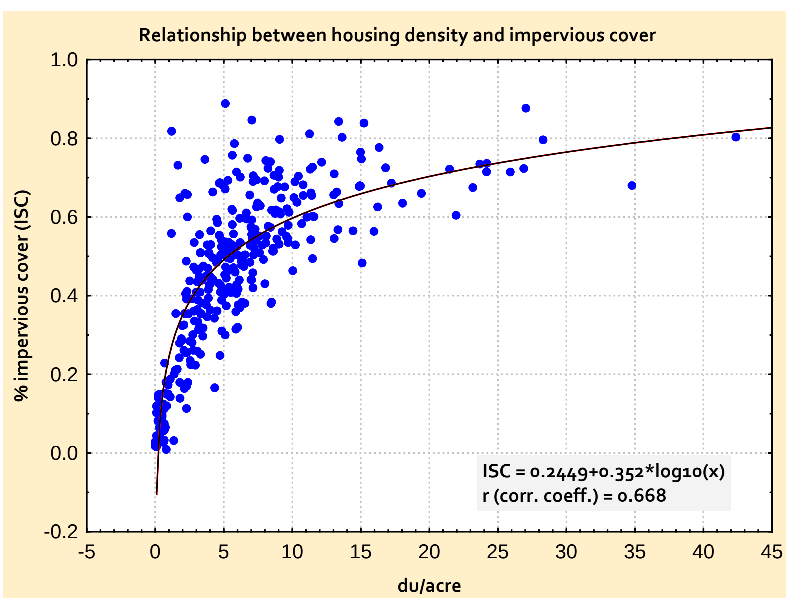

Figure 3. Regression relationship between housing density and percent impervious cover. A logarithmic fit best describes this relationship (ISC = 0.2449 + 0.352 x log density). It reflects that past a certain percent IC, buildings go up, not out. Most communities have requirements for a certain percentage of greenspace for residential housing so adding more units requires building up.

The logarithmic relationship can be linearized by using a semi-log plot (Figure 4), shown below.

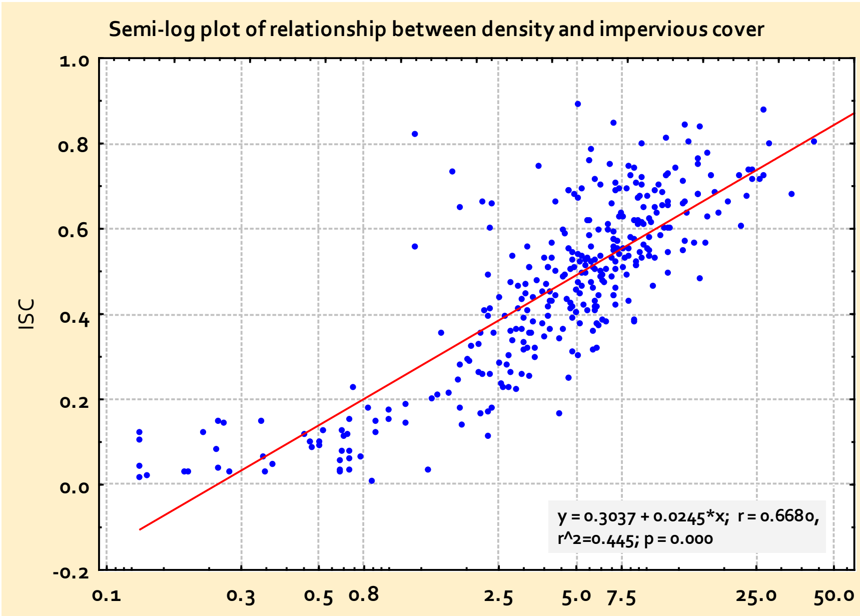

Figure 4. Regression relationship of the log housing density vs. the percent impervious cover. The equation is: ISC = 0/3037 + 0.0245x, where x is the log of the density.

We also investigated various exponential relationships using the Box- Cox transformation to identify the exponent that best fits the data and therefore, the best regression relationship. The Box-Cox procedure transforms the original data in a way that the new variable will have a distribution as close to normality as possible. Through an iterative process, the exponent is identified which minimizes the variability, essentially reducing the noise of the data. For our dataset (n=333), this exponent was 0.3425 and the resulting regression equation is shown in Figure 5.

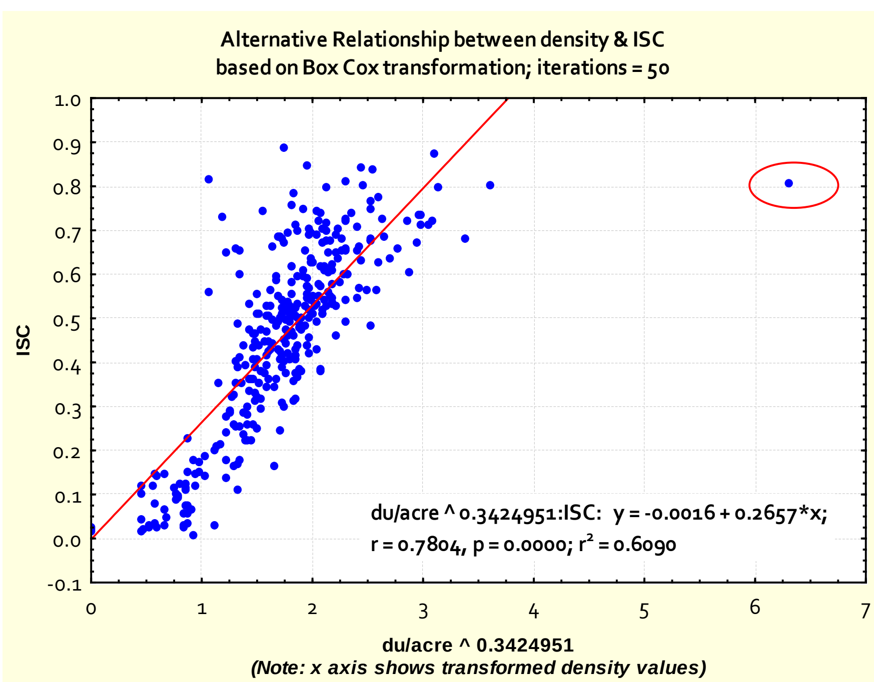

Figure 5. Regression relationship between housing density and percent IC based on Box-Cox transformed data.

The limitation of using an equation based on the transformed data ($y = -0.0016 + 0.2657\ x$, where x is du/acre raised to the 0.3425 power) is that it doesn't accurately describe high density residential housing. Our dataset contained only a single site with high density housing (about 50 du/acre, data point circled in Figure 5). The impervious cover at this high density site in Irvine was about 80 percent, applying the equation above. However, when using the equation in 100 percent. Other sites with high density produced equally unrealistic ISCs. We had an insufficient number of high density sites in our dataset to accurately characterize this high end of the curve. Therefore, until additional analysis is possible, the best equation that describes the relationship between density and ISC is the original equation: **ISC = 0.2449 +0.352*log x.**

Table 2. Residential ISCs.

Residential ISC	
Density (du/acre)	California ISC
0.5	0.14
1	0.24
2	0.35
3	0.41
4	0.46
5	0.49
6	0.52
7	0.54
8	0.56
9	0.58
10	0.60
11	0.61
12	0.62
13	0.64
14	0.65
15	0.66
20	0.70
25	0.74
30	0.76
35	0.79
40	0.81
45	0.83
50	0.84

Table 2 (*right*) provides a look-up table that summarizes the ISC for a wide range of housing densities. The ISC is the decimal value that reflects the percent of any level of residential density that is covered with hardscape.

C. Roads

There were three ISCs developed for roads: urban/suburban roads, rural roads, and highways. A total of 253 local, collector, and arterial roads were identified on the aerial photographs, then analyzed for impervious cover. More specifically, the area (acres) of the right-of-way (ROW, the road itself plus the adjacent land over which local jurisdictions reserve for the purposes of maintenance or expansion of the existing road), was determined either by: a) obtaining a shapefile with a data layer outlining the right-of-way, or b) constructing the polygons that make up the right-of-way by subtracting the area associated with the land use polygons from the total area. What remained is the area associated with the right-of-ways. The results are as follows:

1. Urban/Suburban Roads

Local, collector, and arterial ROWs in urban and suburban areas in Irvine, Santa Cruz, and Sacramento were used to determine the urban/surburban ISC. Because a greater number of sites were analyzed in the Sacramento region than the other two (n= 193 vs. n=60 Irvine & Santa Cruz), our analysis of imperviousness was weighted to reflect this fact. We noted that roads in the Sacramento area tended to have higher ISCs than in Santa Cruz or Irvine. This might be associated with the easy availability of land that has led to an expansive pattern of development in many Central Valley cities. The lower values for arterials in the other cities are likely associated with wider boulevards and landscaped areas adjacent to the sidewalks.

TABLE 3 (below) contains the ISCs calculated for each road type in each city.

Road Type	Sacramento	Irvine	Santa Cruz
Local	88	85	88
Collector	95	87	87
Arterial	89	66	76

Table 3. ISCs for major road types from the three communities.

We used the above ISC values from each city (Table 3) and a weighting factor that reflects the percent of the total ROW area that each road type occupied relative to the total area of roads, to calculate the weighted-average for urban/suburban roads. The distribution of road types were: local roads: 20 percent; collectors: 67 percent; and arterials, 13 percent of the total area of all interior roads (non-highways). This calculation resulted in three ISCs for suburban/urban road as follows:

City	Urban/Suburban ISC
Sacramento area	93%
Irvine	84%
Santa Cruz	86%
Weighted Average	**91%**

Table 4. Percent imperviousness associated with roads in the three study cities.

The overall mean was also calculated using a weighting factor, in this case the weighting reflected the sample size from each city. Data from Sacramento was weighted more heavily due to the larger sample size. The overall weighted mean, and the value we recommend for determining the percent imperviousness associated with roads, is **91 percent**.

2. Rural Roads

The rural roads ISC was based on a sample size of 43 sites along rural roads from Santa Cruz and Sacramento. The same weighted-average approach was used to calculate the mean ISC of 45 percent. One limitation of this approach is that the weighting of the three road types was based on urban/suburban ratios. It is doubtful that this ratio is accurate for rural areas, which are dominated by two lane roads that don't fit neatly into the urban roads categories. Yet, when the simple average was calculated, the results were the same; the ISC was **45 percent**.

3. Highways

Unlike interior roads which can vary from city to city based on local policies and ordinances, highways are overseen by a state department, Caltrans, and standards for construction and design are the same throughout the state. Highway data was analyzed only in Sacramento. Although most people think of highways as the epitome of urban life and hardscape, they have wide right-of-ways as well as large amounts of green space associated with on-off ramps. Consequently, the percent imperviousness for highways is surprisingly low: **47 percent**.

SECTION IV. CALCULATING CURRENT AND BUILD-OUT IMPERVIOUS COVER

Calculating current and build-out (future) impervious cover is a relatively straightforward process, assuming the availability of land-use data layers. Build-out analysis can be easily done on a spreadsheet. The only information required is knowledge of the total acreage for each land-use category within the area of interest. If generalized land-use categories are not available, zoning categories can be used, but will likely require aggregation into more general land use categories comparable to those in Section II.

Calculating current impervious cover is a bit more complicated because it requires information about parcels that currently are not built-out as designated in the general plan. City and county general plans commonly designate land use 20 years into the future, although those lands often have a completely different use at the present time. For example, land could be zoned for office development, but is currently being used as farmland. This is a common occurrence in communities surrounded by greenfields. This section presents the method for performing both sets of IC calculations.

A. Future or Build-Out Impervious Cover

The calculation of impervious cover at build-out, when all lands are developed as specified in the general plan, is very straightforward. It involves multiplying the total acreage for each LUC by the ISC and summing the values for all LUCs. The following example illustrates this process.

Assume the area for analyis is a 1500 acre sub-division (or a watershed, or any other area with identified boundaries) with a single land use, low density residential (ISC=52%) with roads (ISC = 91%). In some cases, the area of the right-of-way is known. In this example, we calculated it, based on the typical patterns found in new development, where ROW accounts for approximately 22% of the total land.

Build-Out Imperviousness:

1. 1500 x .22 (% of development that is ROW) = 330 acres of ROW
2. 330 acre ROW x 0.91 (ISC for suburban roads) = 300 acre impervious ROW
3. Total low density residential (LDR) (5 du/acre use) = 1170 acres
4. 1170 x 0.52 (ISC) = 608 acres of impervious LDR
5. 608 + 300 =908 acres impervious in 1500 acre sub-division.

   Future level of imperviousness = 61%

An Impervious Cover Calculator was developed to facilitate these calculations. This Calculator is available on OEHHA's website(www.oehha.ca.gov/ecotox.html). Using the same hypothetical development described above, a sample calculation using the Calculator is shown below:

	INPUTS				OUTPUTS		
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
	Land Use Category	Total Area (acres)	Non-conforming Area (acres)	Current Conforming Area	Impervious Surface Coefficient	Buildout Impervious Cover (acres)	Current Impervious Cover (acres)
Residential	6 du/acre residential	1170			0.52	607	0
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
Non-Residential	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
Roads	Urban/Suburban	330			0.91	300	0
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
	Nonconforming Land Uses (acres)						
Nonconforming Land Uses	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	TOTAL ACRES	1500	0	0			
				TOTAL IMPERVIOUS ACRES		907	0
				PERCENT IMPERVIOUSNESS		60	0

To use the Calculator, identify the land use categories within the geographic area of interest. A drop-down menu is provided for residential, non-residential, and road land uses. For residential, select the density of the development, input the acres of that particular LUC, the impervious surface coefficient and total impervious acres are then calculated. For non-residential uses and roads, a similar drop-down menu is available for selecting the appropriate LUC and other input parameters.

B. Current or Transitional Impervious Cover

To determine the current amount of imperviousness, additional steps are needed to account for the current use of lands that might be designated for different uses. We identify these parcels as **non-conforming** because they are not being used in accordance with their General Plan designation. For example, an area designated as medium density residential may instead be currently used for irrigated agriculture or rural residential.

Before using the ISC, a series of checks should be performed to correct for non-conforming parcels. They include:

- Adjustment of non-conforming parcels
- Identification of vacant lots
- Adjustment of the build-out impervious acres to reflect current use, using the non-conforming parcel correction factor (NPCF).

Step 1: Identify and recategorize non-conforming parcels

To determine the current amount of imperviousness within a given area, non-conforming parcels must be re-categorized based on their existing use. By re-categorizing the non-conforming LUC acreage, the total area of the designated future LUC is adjusted to reflect the current or transitional land use.

Step 1a: Visual Inspection of Aerial Photographs

The simplest method for identifying non-conforming parcels is to visually inspect each land use category for the presence of inappropriate land uses. In the majority of cases, the non-conforming use is less developed than their designation in the general plan; they are relatively easy to identify using a high resolution orthophotograph and a land use data layer. Depending on the state of development, it is easiest to track either a) those parcels that conform to the designated land use OR b) those that do not. As the current land uses are identified the records in the attribute file of the GIS project should be updated to reflect the land use shown in the aerial. Thus the date the aerial was taken should guide the selection of the land use layer.

Figure 6. A Non- Conforming Parcel. This house was designated as low density residential in the land use layer, yet it is on a three acre parcel, a density better characterized as rural residential. The ISC for this parcel must be adjusted to reflect current conditions.

For non-conforming parcels in transition due to redevelopment or down zoning such as conversion of former industrial sites to residential, use the descriptions in Section II of the User's Guide for suggestions on how to reclassify a land use that does not conform to its identified type and description. During the adjustment of the non-conforming parcels it may be difficult to determine the designated use of vacant or fallow land. **Vacant Land** is property that*, in its entirety*, is not being used for its designated use.

Best practices would be to:

- Look at the size, configuration, and surrounding land uses to help determine the vacant lot land use. A non-conforming area that is small in size and has a shape similar to its neighborhood's is likely an undeveloped sub-division or commercial park.
- Do not re-classify vacant parcel with commercial, planned open space and recreation, or residential uses. This circumstance will be addressed in Step 2 (below).
- Re-categorize working lands (agriculture) if the general plan contemplates more intense use. Differentiating between agricultural land and planned open space, such as a nature

reserve, is sometimes difficult. Comparing the size of the parcel to surrounding lands is one way to identify planned open space. Nature reserve/open space is often cross-cut by trails or natural groupings of vegetation, features rarely seen in agricultural parcels. It will likely be sized larger and shaped differently from surrounding parcels. On the other hand, agricultural land likely will sit nearby other agricultural land, and possess visible signs of the land being worked, such as rows of plantings or trees and narrow dirt roads neatly bisecting property.

Step 1b: Non-Visual Identification of Non-Conforming Parcels that are Vacant

A non-visual method can be used to identify non conforming parcels that are vacant. This approach relies on obtaining data from the appropriate local government department to identify vacant parcels. This information may be found in one or more of the following databases:

- The Housing Element in a General Plan or General Plan Update contains a vacant land inventory. The inventory contains the Assessor's Parcel Number (APN), the size of the parcel, and the LUC for which it is zoned. The total acreage for each LUC can be used to determine the amount of vacant land in each land use. However, as General Plans are updated every five years or more, this inventory may be out of date.
- The County Assessor's Office maintains a list of parcels with their assessed values that are calculated by combining the value of the land and the structure(s) on it. Lots with nominal or no improvement value are likely vacant. Generally, structures such as schools, churches, and government building are not assessed by the county, so they have no assessed improvement value. This circumstance is most commonly seen in the Public/Quasi Public and Open Space LUCs. Identify these land uses on the aerial photograph when determining if an area is vacant.

Whether the visual inspection method or a combination of visual inspection and reviewing of local databases are used to identify the area of vacant land within each LUC, efforts should be made to match the date of the assessor's data with the date of the aerial.

Step 2: Application of the Non-Conforming Parcel Correction Factor (NPCF)

After adjusting the land-use layer for the current or transitional use and identifying vacant lots, the area of non-conforming parcels is subtracted from the total. Then the calculation of impervious cover can be performed in a similar way as for build out, i.e. by multiplying the total acreage for each LUC by the ISC and summing all values.

The sample calculation below illustrates how to perform an analysis of current conditions.

Assume the area for analyis is the same 1500 acre sub-division (or watershed, or any other area with identified boundaries) used above for the build-out calculation, ie., with a single land use, low density residential (ISC=52% with roads ISC = 91%).

Current Imperviousness

1. 1500 x .22 (% of development that is ROW) = 330 acres of ROW
2. Total low density residential (LDR) (5 du/acre use) = 1170 acres
3. 1170 LDR acres - 400 acres of non-conforming land that is vacant *(NPCF)* = 770 acres developed
4. 770 x 0.49 = 378 acres of impervious LDR
5. 330 acre ROW x 0.91 (ISC for suburban roads) = 300 acre impervious ROW
6. 378 + 300 = 678 acres impervious in 1500 acre sub-division

   Current level of imperviousness = 45 %

	INPUTS				OUTPUTS		
	Column 1	*Column 2*	*Column 3*	*Column 4*	*Column 5*	*Column 6*	*Column 7*
	Land Use Category	Total Area (acres)	Non-conforming Area (acres)	Current Conforming Area	Impervious Surface Coefficient	Buildout Impervious Cover (acres)	Current Impervious Cover (acres)
Residential	6 du/acre residential	400		400	0.52	208	208
	1 du/acre residential	200		200	0.24	49	49
	1 du/acre residential	200		200	0.24	49	49
	[Select LUC Here]				0.00	0	
	[Select LUC Here]				0.00	0	
Non-Residential	[Select LUC Here]				0.00	0	
	Agriculture	0			0.04	0	
	[Select LUC Here]				0.00	0	
Roads	Urban/Suburban	150		150	0.91	137	137
	Rural	50		50	0.43	22	22
	[Select LUC Here]				0.00	0	
	Nonconforming Land Uses (acres)						
Nonconforming Land Uses	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	[Select LUC Here]				0.00		0
	TOTAL ACRES	1000	0	1000			

TOTAL IMPERVIOUS ACRES	463	463
PERCENT IMPERVIOUSNESS	46	46

Use the Calculator to perform this calculation as illustrated above. The 400 acres that are identified under the 5 du/acre land use category were determined to be rural residential land that was non-conforming. Those 400 acres were then listed as 0.5 du/acre under the land use category and a new calculation at 14% IC was performed for those acres at 0.5 du/acre. Factoring in the imperviousness associated with roads, the total impervious acres added up to 734 out of 1900 or 39% IC currently.

In summary, calculation of impervious cover at build-out is a simple process that can be performed using a spreadsheet, assuming the areas of the pertinent land uses are known. Analysis of current conditions becomes slightly more complicated because non-conforming land uses must be identified and adjustments made to the acreage of relevant LUCs.

Appendix 1: Comparison of Impervious Cover for Residential Land Uses in 3 Study Cities

City of Irvine LUC	Irvine Description	City of Irvine ISC	SACOG LUC	SACOG Description	SACOG ISC	City of Santa Cruz LUC	SC description	City of Santa Cruz ISC
Estate Density	0-1 du/ac	Not Analyzed; Too few parcels	**Rural**	0-1.0 du/ac	6	**Very-Low Density**	0.1-1 du/ac	12
Low Density	1.1-5 du/ac	43	**Very Low Density**	1.1-4.0 du/ac	30	**Low Density**	1-10 du/ac	46
			Low Density	4.1-8.0 du/ac	44			
Medium Density	5.1-10 du/ac	61	**Medium Density**	8.1-12.0 du/ac	53			
Medium-High Density	10.1-25 du/ac	72				**Low-Medium Density**	10.1-20 du/ac	52
			Medium-High Density	12.1-25 du/ac	53			
						Medium Density	20.1-30 du/ac	68
High Density	25.1-40 du/ac	69	**High Density**	25.1-50 du/ac	67			
						High Density	30.1-55 du/ac	Not used n=1
			Urban	50.1-100+ du/ac	Not Available			
			Medium-High Density	12.1-25 du/ac	53			

Appendix 2: Comparisons of Impervious Cover for Non-Residential Land Uses in 3 study cities

City of Irvine			SACOG			City of Santa Cruz		
LUC	**Description**	**ISC**	**LUC**	**Description**	**ISC**	**LUC**	**Description**	**ISC**
Neighbor-hood Commercial	Any retail/business serving immediate neighborhood	87	**Community/ Neighbor-hood Retail**	(0.2-0.3 FAR)[2] 100% Retail	80	**Neighbor- hood Commercial**	(0.25-1.5 FAR) Small-scale commercial serving residential neighborhoods	87
Regional Commercial	Shopping/retail areas with regional scope (includes office uses)	86	**Regional Retail**	(0.2-0.3 FAR) 95% Retail 5% Office	82	**Community Commercial**	(0.25-1.75 FAR) Retail & services serving needs of the local community	93
Vehicle Commercial (Not a LUC category, but a zoning category)	Fast food rest., car dealerships, rentals, and vehicle storage	87				**Regional Visitor Commercial**	(0.25-3.5 FAR) Commercial uses that serve Santa Cruz residents as well as visitors	89
Community Commercial	Industry or business that serves the community (includes office uses)	77						
N/A			N/A			**Coastal Development**	coastal commercial development	23
Retail/ Office (Not a LUC in Irvine, but created from a subset of LUC during analysis)	subset of Community and regional office uses are subcategories of commercial categories	76	**Moderate-Intensity Office**	(0.3-1.0 FAR) 5% Retail and 95%Office	68	**Office**	(0.25-1.75 FAR) Small-scale office uses and mixed-use projects	65
			High-Intensity Office	(1.1+ FAR) 5% Retail and 95%Office	85			

[2] FAR refers to floor-area ratio, the ratio of the total floor area of a building to the size of the land at that location.

SECTION V. APPLICATION OF THE COEFFICIENTS TO STORMWATER RUNOFF CALCULATIONS

A. Introduction

Impervious surface coefficients can be used to estimate stormwater runoff. Unlike suburban land use patterns found throughout the U.S., California's suburbs are typically denser with more dwelling units per acre of land. Consequently, use of non-California ISCs can underestimate the amount of impervious cover at low residential densities, leading to an underestimation of the volume of stormwater runoff. In other cases, non-California ISCs may overestimate runoff from a site, such as office parks. This chapter describes how California ISCs were used to develop a set of alternative curve numbers (CN) and how they can be applied to estimate storm water runoff.

B. Overview of the Curve Number and Curve Number Method

Developed by the National Resource Conservation Service (NRCS), the Curve Number Method is widely used to estimate stormwater runoff. This method assumes that impervious areas are connected via a stormwater conveyance system (e.g. storm drain) so that almost all of the rain that falls on impervious areas will become runoff. The runoff calculation is dependent on the amount of precipitation, the CN, and soil moisture before a storm event (antecedent moisture conditions). In addition to antecedent soil moisture conditions, four hydrologic soil groups, based on the porosity of soil, are also considered in the calculation. The CN itself is a unit-less parameter, usually ranging between thirty and one hundred, derived from the amount of impervious cover. A lower CN value indicates the area will have less runoff and more soil infiltration; conversely, a higher CN value suggests a larger amount of runoff.

Hydrologic Soil Groups (HSG)

HSGs are classified into four groups. These groups are divided by infiltration rates.

Group A – Infiltration rate greater than 0.3 in/hr.
Mostly sand or gravel soils.
Low runoff potential.

Group B – Infiltration rate 0.15 to 0.30 in/hr.
Moderately coarse soils.

Group C – Infiltration rate 0.05 to 0.15 in/hr.
Moderately fine to fine soils.
Can impede water flow.

Group D – Infiltration rate is less than 0.05 in/hr
Mostly fine soils (clays).
High runoff potential.

The Curve Number Method

Stormwater runoff estimates are calculated as follows:

$$S = (1000/CN) - 10$$

Where:

S = the potential abstraction (maximum potential retention of water by the soil after runoff begins)
CN = the CN for the given LUC and HSG

Once the potential abstraction has been calculated, it can be used in the following equation:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

Where:

Q = depth of runoff (inches)
P = precipitation (inches)
S = the potential abstraction

To produce runoff, P must be greater than 0.2S. If P is less than or equal to 0.2S, then the runoff amount is essentially zero. When P is greater than 0.2S, multiplying the Q value by the area of the site gives the volume of runoff produced.

C. Derivation of California Curve Numbers

An alternative set of curve numbers were developed, using OEHHA's California ISCs for residential and non-residential development as well as roads. The following equation is used to calculate these values:

$$CN = [(CN_{OS}) \times (1 - ISC_i)] + [(98) \times (ISC_i)]$$

Where:

CN_{OS} = the runoff potential of the soil assuming the area is open space (OS), in good hydrologic condition, and that the soil is not frozen; the four CN_{OS} for HSGs A, B, C, and D (see text box above) are 39, 61, 74, and 80, respectively (National Engineering Handbook, 2004),

1-ISC = the percent of land use category *i* that is pervious,

98 = maximum potential runoff,

ISC = the percent of land use category *i* that is impervious.

The NRCS ISCs and CNs identify six residential densities ranging from ½ to 8 du/acre, with no values provided for residential densities greater than 8 du/acre. While these values reflect low or medium density development patterns in many California cities, some medium or high density developments in California contain 12, 15 or even 20 du/acre. The more limited range of densities used to develop the original NRCS curve numbers could lead to an under-estimation of potential runoff from higher density developments.

Table 5 illustrates similarities and differences between the ISCs used by the NRCS and those developed by OEHHA. Dashes indicate no NRCS value is available. The NRCS classification scheme only provides two categories for non-residential development. One ISC and CN value for the commercial/business LUC and one for the industrial LUC are available. In California, however, most cities have multiple commercial and industrial LUC with different amounts of impervious cover. OEHHA developed CNs for three commercial, two industrial, and two office LUCs which are reflective of varying amounts of impervious cover for each land use type.

Table 5. California and NRCS Impervious Surface Coefficients for Non-Residential and Residential Land Uses

Non-Residential ISCs		
Land Use	**California ISC**	**NRCS ISC**
Retail	0.86	0.72
Retail/Office	0.80	0.72
Coastal Development	0.23	--
Office Park	0.69	0.72
Urban Office	0.86	0.72
Light Industry	0.81	0.85
Heavy Industry	0.91	0.85
Public/Quasi-Public	0.44	--
Mixed Use	0.80	--
Open Space	0.02	--
Agriculture	0.04	--

Residential ISCs		
Density (du/acre)	**California ISC**	**NRCS ISC**
0.5	0.14	0.12
1	0.24	0.20
2	0.35	0.25
3	0.41	0.30
4	0.46	0.38
5	0.49	0.38
6	0.52	0.38
7	0.54	0.38
8	0.56	0.65
9	0.58	0.65
10	0.60	0.65
11	0.61	0.65
12	0.62	0.65
13	0.64	0.65
14	0.65	0.65
15	0.66	0.65
20	0.70	0.65
25	0.74	0.65
30	0.76	0.65
35	0.79	0.65
40	0.81	0.65
45	0.83	0.65
50	0.84	0.65

Table 6 contains CNs for hydrologic soil group A, the most pervious soil classification. The CNs are based on the CA set of impervious surface coefficients. Look up tables for all 4 hydrologic soil groups can be found in the Appendices to this section.

Table 6. Comparison of California and NRCS curve numbers for residential and non-residential land uses.

Non-Residential CN for HSG A		
LUC	**California CN**	**NRCS CN**
Retail	90	89
Retail/Office	86	89
Coastal Development	53	89
Office Park	80	89
Urban Office	89	89
Light Industrial	87	81
Heavy Industrial	93	81
Public/Quasi-Public	69	-
Mixed Use	86	-
Open Space	40	39
Agriculture	41	Varies
Roads		
Urban/Suburban	93	98
Rural	64	83
Highways	69	83

Residential CN for HSG A		
Density (du/acre)	**California CN**	**NRCS CN**
0.5	47	46
1	53	51
2	60	54
3	63	57
4	66	61
5	68	61
6	70	61
7	71	61
8	72	77
9	73	77
10	74	77
11	75	77
12	76	77
13	77	77
14	77	77
15	78	77
20	80	77
25	82	77
30	84	77
35	86	77
40	87	77
45	88	77
50	89	77

D. Using the California ISCs and CNs: An Example

A runoff calculation is presented here for a hypothetical 100 acre development using both the NRCS and California CNs. The following assumptions were made for this purpose:

- One inch rain event
- 100 acre parcel divided into four major LUCs and roads:
  - Residential (55 acres)
  - Office park (10 acres)
  - Retail (10 acres)
  - Open space/parks (5 acres)
  - Right of way for roads and sidewalks (20 acres)
  - The 55 acre residential area divided equally into three 18.33 acre residential LUCs of 4, 10, and 20 du/acre (LDR, MDR, and HDR, respectively)

Because the NRCS handbook does not provide ISC or CN values for residential densities greater than 8 du/acre, the closest value provided for a comparable LUC (8 du/acre) value was used for all densities greater than 8 du/acre. Also, the NRCS commercial/business CN was applied to the retail LUC. The commercial CN was applied to offices and office parks since the NRCS does not provide any values for these LUCs. Using the CA ISCs and CN values for the four hydrological soil groups (HSGs), we calculated stormwater runoff amounts for the same development scenario built on the different HSGs. Figures 7 – 10 highlight the total and individual LUC calculated runoff volumes, converted to acre-feet.

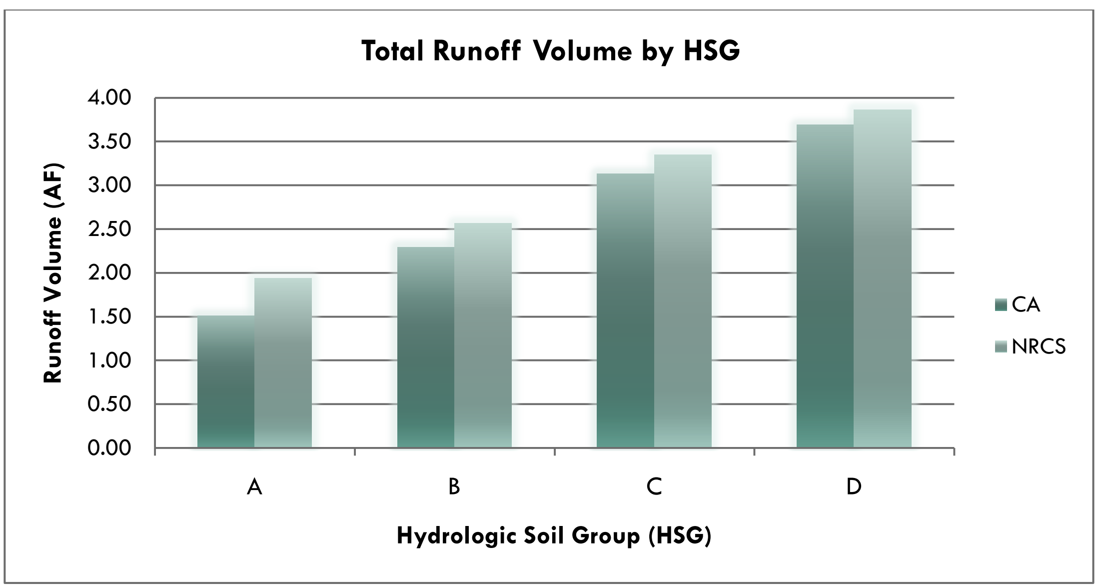

Figure 7 . Total runoff volume by HSG for a 1" rain event on a 100 acre development.

Figure 7 illustrates the differences in total runoff for the development using the California and NRCS CNs. The differences between the California and NRCS runoff estimates are greatest when soils are more permeable (HSG A). In HSG A, the NRCS runoff estimate is 20% greater than the

California runoff estimate. In other words, the California and NRCS estimates differ by 0.43 acre-feet (approximately 140,000 gallons). When the native soil has low permeability (HSG D), the NRCS runoff estimate is only 3% greater than the estimates based on the California CNs. For the HSG D scenario, the difference was 0.17 acre-feet or approximately 55,000 gallons. The differences in runoff are 5.5% and 4% respectively for HSGs B and C.

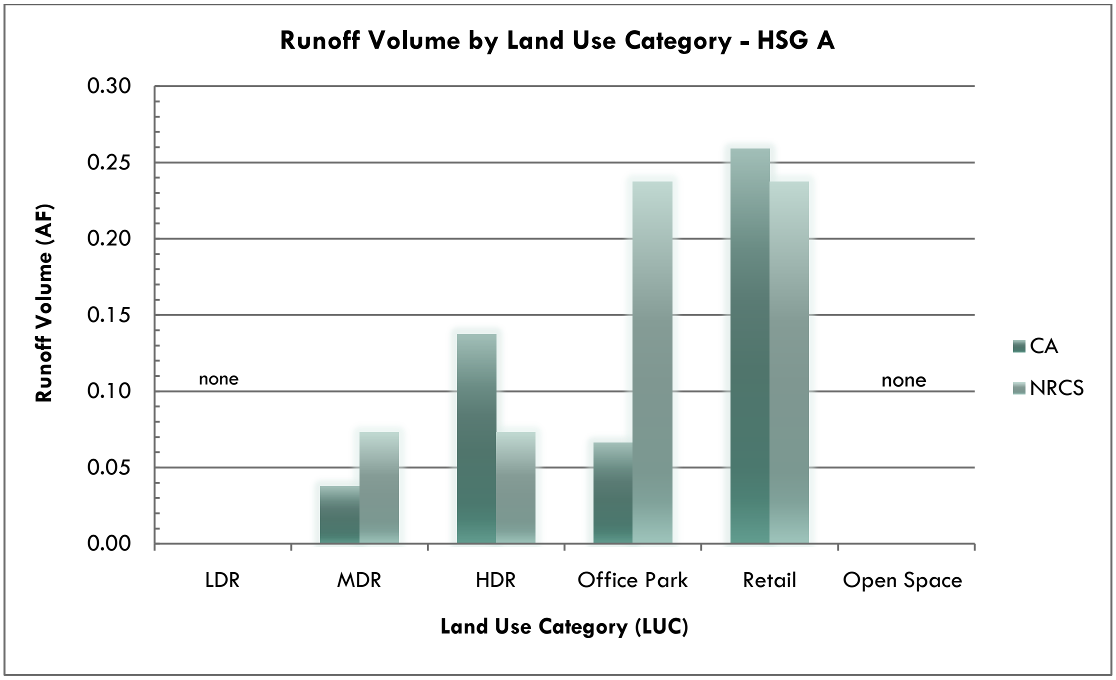

Figure 8. Runoff volume by land use category (excluding roads) for HSG A. Each bar represents the volume of runoff in acre-feet (AF) for the hypothetical 100 acre development. Values were calculated using the California (CA) and NRCS set of curve numbers. LDR = low density residential, MDR = medium density residential, HDR = high density residential. Due to the high permeability of Type A soil, there was no runoff from the LDR or Open Space LUCs.

As illustrated in Figure 8, the differences between the C and NRCS CN are greatest in highly permeable soils, where the differences in the ISC values can be detected easily. For example, there is 3.5-fold less runoff volume for the Office Park LUC when using the California CNs. This difference is linked to the fact that office parks have less impervious cover than most commercial LUCs. The opposite is true for high density residential where the estimate of runoff using the California CN yields about two-fold greater runoff volume.

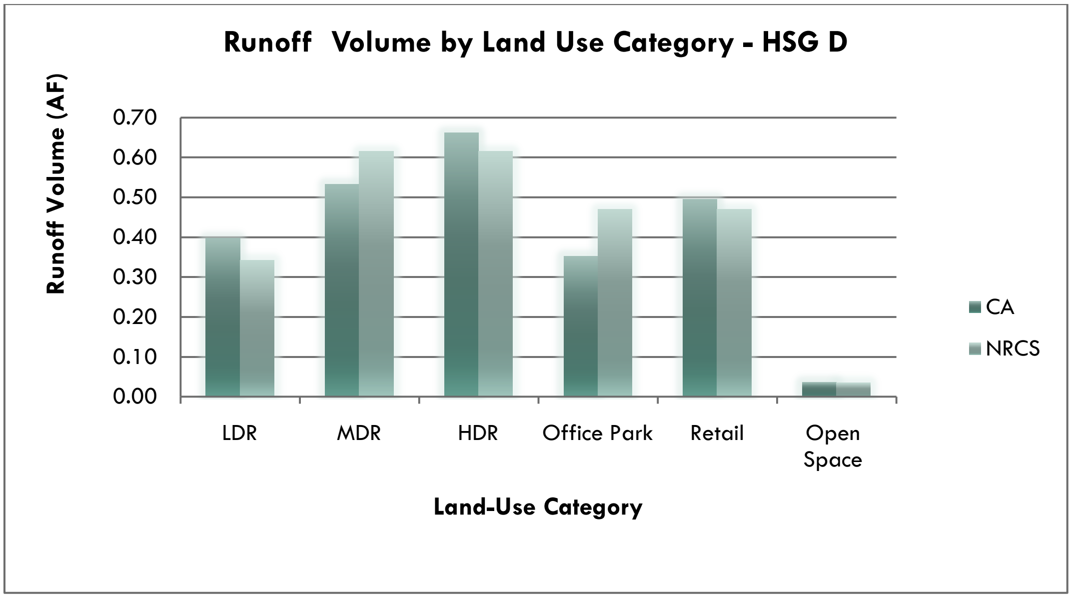

Figure 9. Runoff Volume by LUC for HSG D. Abbreviations are the same as for Figure 8.

Figure 9 illustrates the same relationships but for HSG D, which has much less permeability than HSG A. Due to the reduced difference between bare soil and impervious cover in D soils, runoff volume for Office Park is 1.3-fold greater compared to 3.5 for HSG A using the NRCS CN and California CNs. In contrast, runoff from HDR is just 15% larger than estimated using the NRCS CN compared to approximately 50% for HSG A. The total runoff volume is about 10% greater when using the NRCS CNs than with the California values.

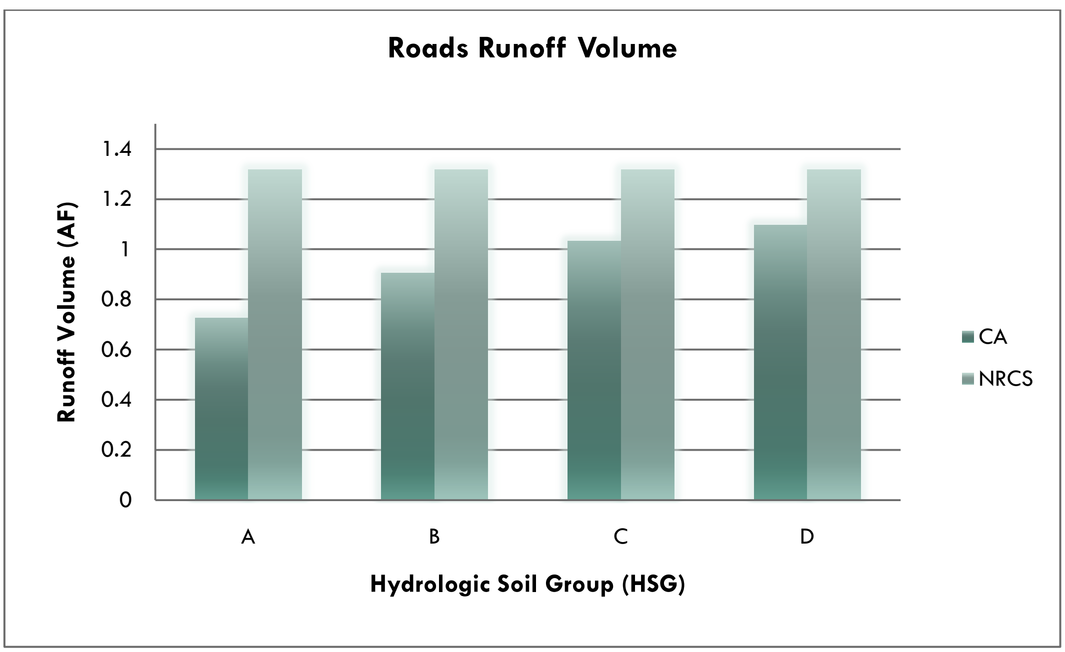

Figure 10. Runoff volume from right-of-way (roads) for all soil types.

Figure 10 illustrates differences in stormwater runoff from roads. The pattern is similar to the previous comparisons; the differences between the two runoff volumes are greater for more porous soil. For HSG A, use of the California CN would yield 38% less runoff from roads than the volume calculation using the NRCS value. This difference diminishes to 13% (for HSG D) as the soil becomes less pervious. Overall, runoff volumes are consistently lower when using California CNs.

Although not evident from this example, the differences in road runoff would be even larger if the area of analysis included rural roads and highways. The following table illustrates the percent reduction in runoff using California and NRCS CNs for the 4 hydrologic soil groups for the 3 major road categories.

	Percent reduction in runoff volume from roads using California CNs			
Road Type	***HSG-A***	***HSG-B***	***HSG-C***	***HSG-D***
Suburban/Urban	3.2	3.2	2.0	2.0
Rural	23	13	8.7	5.4
Highway	19	12	7.6	4.3

Table 7. Estimated reduction in roadway stormwater runoff when calculating volume using the California CNs compared to the NRCS CNs. The values reflect the percent reduction in the runoff volume. CN for highways are not available from the NRCS. Therefore, when estimating runoff volumes, we made the assumption that NRCS CN for highways has the same CN as rural roads because rural roads typically do not have storm drains as is the case for highways. These estimates are on the conservative side for a few reasons: a) many locations in California are hilly which would increase actual runoff, and b) California has many higher intensity land uses than those provided by the NRCS.

D. Conclusion

The California CNs support accurate estimations of stormwater runoff. The California ISC and companion CNs can be used as a tool for sizing stormwater facilities of all types. They can also be used to help implement hydromodification management plans which call for no net change or limited change in the hydrograph post-development. Use of the ISC is one of the most accurate ways to estimate current levels of runoff, laying the basis for determining the size of bioretention cells, detention/retention basins, and swales needed to prevent changes in the hydrograph. In addition to meeting regulatory requirements, appropriate sizing of stormwater management structures helps ensure they are cost-effective.

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Appendix A: Non-Residential Curve Numbers

The following set of look up tables provide a quick reference for the set of Non-Residential CA CNs for the 4 hydrologic soil groups.

HSG A - Non-Residential CN		
LUC	**California CN**	**NRCS CN**
Retail	90	89
Retail/Office	86	89
Coastal Development	53	89
Office Park	80	89
Urban Office	89	89
Light Industrial	87	81
Heavy Industrial	93	81
Public/Quasi-Public	69	-
Mixed Use	86	-
Open Space	40	39
Agriculture	41	Varies
Roads		
Urban/Suburban	93	98
Rural	64	83
Highways	69	83

HSG B - Non-Residential CN		
LUC	**California CN**	**NRCS CN**
Retail	93	92
Retail/Office	91	92
Coastal Development	70	92
Office Park	87	92
Urban Office	92	92
Light Industrial	91	88
Heavy Industrial	95	88
Public/Quasi-Public	80	-
Mixed Use	91	-
Open Space	62	61
Agriculture	62	Varies
Roads		
Urban/Suburban	95	98
Rural	77	89
Highways	78	89

HSG C - Non-Residential CN		
LUC	**California CN**	**NRCS CN**
Retail	95	94
Retail/Office	93	94
Coastal Development	80	94
Office Park	91	94
Urban Office	94	94
Light Industrial	93	91
Heavy Industrial	96	91
Public/Quasi-Public	86	-
Mixed Use	93	-
Open Space	74	74
Agriculture	75	Varies
Roads		
Urban/Suburban	96	98
Rural	84	92
Highways	85	92

HSG D - Non-Residential CN		
LUC	**California CN**	**NRCS CN**
Retail	95	95
Retail/Office	94	95
Coastal Development	84	95
Office Park	92	95
Urban Office	95	95
Light Industrial	95	93
Heavy Industrial	96	93
Public/Quasi-Public	89	-
Mixed Use	94	-
Open Space	80	80
Agriculture	81	Varies
Roads		
Urban/Suburban	96	98
Rural	88	93
Highways	89	93

Appendix B: Residential Curve Numbers

The following look-up table provides a quick reference for residential curve numbers.

HSG A - Residential CN		
Density (du/acre)	California CN	NRCS CN
0.5	47	46
1	53	51
2	60	54
3	63	57
4	66	61
5	68	61
6	70	61
7	71	61
8	72	77
9	73	77
10	74	77
11	75	77
12	76	77
13	77	77
14	77	77
15	78	77
20	80	77
25	82	77
30	84	77
35	86	77
40	87	77
45	88	77
50	89	77

HSG B - Residential CN		
Density (du/acre)	California CN	NRCS CN
0.5	66	65
1	70	68
2	74	70
3	76	72
4	78	75
5	79	75
6	80	75
7	81	75
8	82	85
9	82	85
10	83	85
11	84	85
12	84	85
13	85	85
14	85	85
15	85	85
20	87	85
25	88	85
30	89	85
35	90	85
40	91	85
45	92	85
50	92	85

HSG C - Residential CN		
Density (du/acre)	**California CN**	**NRCS CN**
0.5	77	77
1	80	79
2	82	80
3	84	81
4	85	83
5	86	83
6	86	83
7	87	83
8	88	90
9	88	90
10	88	90
11	89	90
12	89	90
13	89	90
14	90	90
15	90	90
20	91	90
25	92	90
30	92	90
35	93	90
40	93	90
45	94	90
50	94	90

HSG D - Residential CN		
Density (du/acre)	**California CN**	**NRCS CN**
0.5	83	82
1	84	84
2	86	85
3	87	86
4	88	87
5	89	87
6	89	87
7	90	87
8	90	92
9	90	92
10	91	92
11	91	92
12	91	92
13	91	92
14	92	92
15	92	92
20	93	92
25	93	92
30	94	92
35	94	92
40	95	92
45	95	92
50	95	92

SECTION V. APPLICATION OF THE IMPERVIOUS SURFACE COEFFICIENTS TO NATURAL RESOURCES MANAGEMENT

A. Introduction

It has been recognized for many years that when impervious cover increases, conditions of the aquatic ecosystem decline. Impervious cover can affect the diversity and abundance of benthic macroinvertebrates (insects that spend part of their life in the streambed) and fish, habitat conditions such as canopy cover, percent fines in bedded sediment, stability of stream banks and beds, and water quality (summarized in a review by OEHHA, 2009). For these reasons and others, quantifying the amount of impervious cover has become a valuable indicator of watershed conditions.

Since impervious cover serves as a surrogate for disturbance, percent IC has also been used to identify reference streams, those to which conditions of streams can be compared. Recognizing that there are few if any pristine waterways remaining in California, those streams located in less disturbed watersheds can be used as reference points for waterways found in more disturbed areas.

Impervious surface coefficients can be used to estimate the amount of impervious cover within a watershed, within a sub-watershed, and even within stream buffers. In urbanized areas with storm drain conveyance systems, runoff from distant areas within the watershed can impact conditions in the waterway. In areas that do not have a storm drain system, imperviousness within a buffer appears to have a greater impact on the conditions in a stream than IC in the watershed overall (Brabec, 2002; Snyder et al., 2005). This chapter reviews the application of the ISC to the estimation of IC at various areal extents, with the goal of better understanding watershed conditions and improving watershed management.

B. Calculating Imperviousness within Watersheds

A common application of impervious cover analysis is to estimate total watershed imperviousness. The relationship between IC and stream quality and its usefulness as an indicator of potential hazard was highlighted by Schueler (1995). A geographic information system (GIS) offers the easiest way to calculate IC in a watershed or sub- watershed. The process is almost identical to that of calculating current imperviousness, with the exception that the watershed boundary defines the areal extent of the analysis. This analysis requires two key data layers: a map of the watershed boundaries and land-use maps from all relevant municipalities. If the analyst plans to calculate current IC by visually identifying non-conforming parcels for which alternative ISC should be used, then an aerial photograph will also be required.

The data can be obtained in a few different ways:

- If you have GIS capabilities, the data layers mostly reside in the public domain, so local municipalities or regional councils of government usually will make them available.
- In some cases, city staff may assist with the analysis. Because most planning departments work with GIS data, staff may have the capacity to sum up the total acreage in each

land-use category within a defined boundary. This will require providing staff with the boundary of the watershed that falls within the city limits. The outputs from various municipalities can be assembled into a single spreadsheet to determine the build-out impervious acreage by LUC.

- Frequently, paper maps are available which contain the information needed to calculate the acreage of each land use category within different neighborhoods. The watershed boundary can be outlined and manual estimates can be made of the total acreage of each LUC, one of the inputs for the calculation of IC.
- With these data in hand, the Impervious Cover Calculator (ICC) can be used to perform the calculation for build-out. The method was reviewed in Section III, Calculating Current and Future Impervious Cover. Current imperviousness is more relevant because this metric can be correlated with habitat and biological conditions within the waterways. The details of the method for calculating current IC can be found in Section III. An example of a map of current percent IC is shown in Figure 11, in which sub-watersheds were grouped into 3 categories that reflected low, medium, and high levels of impervious cover.

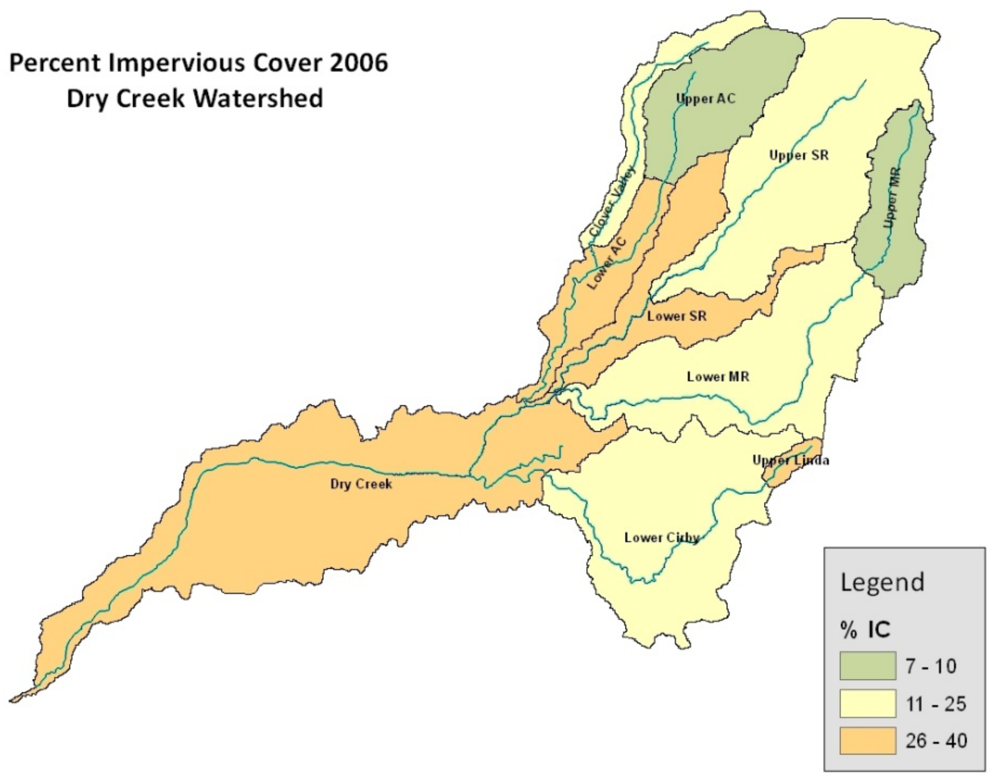


Figure 11. Current Impervious Cover in Dry Creek Watershed

C. Calculation and Application of Impervious Cover Data within a Stream Buffer

The IC within a stream or riparian buffer is another metric of interest to many natural resource managers and those concerned about watershed health. It can serve as an important predictor of the condition of the aquatic ecosystem (Brabec, 2002), especially where buffer disturbance can directly impact conditions in the waterway. The ISC can be used to estimate impervious cover within a stream buffer for approximately 2 acres or larger (discussed in detail below).

Figure 12 illustrates an analysis of % IC within 2 stream buffers having a width of 100 and 1,000 feet. This example is drawn from data on the Dry Creek watershed, a 100 square mile watershed in the foothills east of Sacramento. The shaded, thin, inner lines around the waterways reflects the 5 categories of IC in the 100 foot buffer; the wider shaded line reflects IC in the 1,000 foot buffer, while the shading in the larger sub-watershed reflects 3 levels of overall IC. In general, IC in the 100 foot buffer was quite low, although in one degraded sub-watershed, greater than 20 percent IC was identified. Percent IC in the 1,000 foot buffer generally reflected the overall IC in the sub-watershed. Later in this section, these estimates will be related to metrics measuring the health of benthic macroinvertebrates, useful indicators of the health of the aquatic ecosystem.

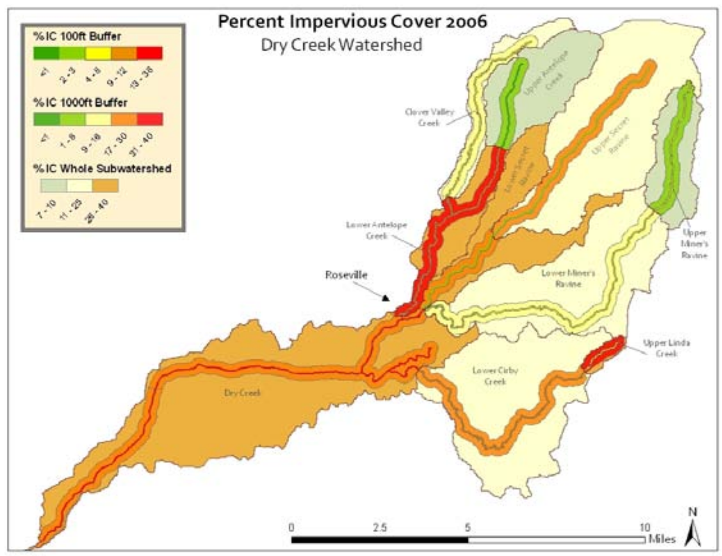


Figure 12. Percent IC in the 100 and 1000 foot buffer by sub-watershed.

The Issue of Spatial Scale when Using the ISCs

The ISCs were not designed for analysis on smaller spatial scales. This can become an issue when looking at IC in a narrow stream corridor, because buildings are typically not randomly distributed on a streamside parcel. Buildings are usually situated out of the 100 year floodplain and away from water. The narrower the buffer, the more difficult it becomes to analyze impervious cover. To investigate this potential limitation, all impervious surfaces within 100 feet of a waterway in 5 sub-watersheds within the Dry Creek watershed were analyzed. Current IC within the 100 foot buffer was calculated in 2 ways: a) using the ISC with data on the areal extent of each land use category within the buffer, then correcting for non-conforming use, as described in Section III, and b) digitizing all impervious cover from high resolution aerial photographs (1 foot resolution) and comparing the results. In each case, estimates of the area derived from using the ISCs in a calculation were double that obtained from direct digitizing off of aerial photos. The results of this analysis are summarized below.

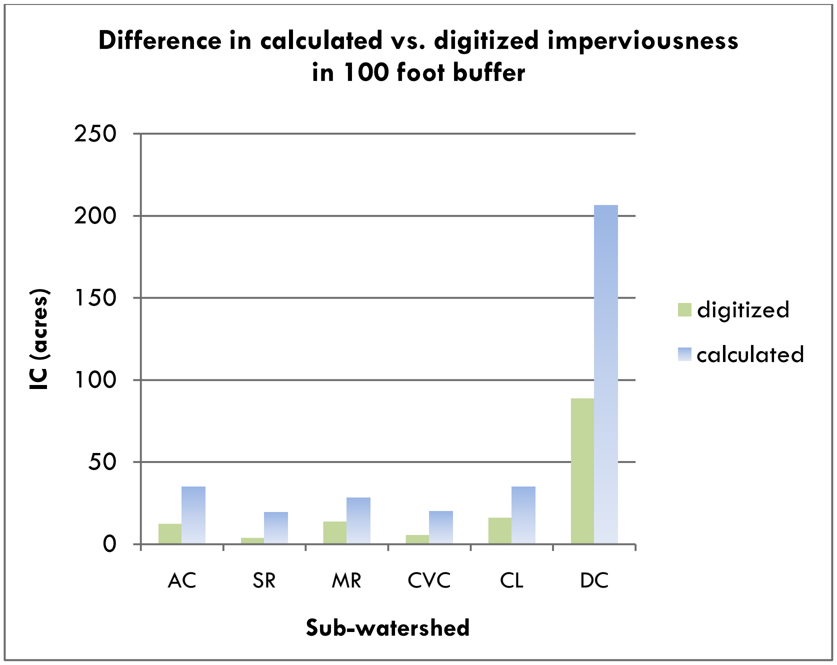


Figure 13. Differences in % IC in the 100 foot buffer using two methods of calculation. The percent IC was determined digitizing all hardscape and by calculation with the ISCs (summation of the area of IC in each sub-watershed x ISC for each LUC).

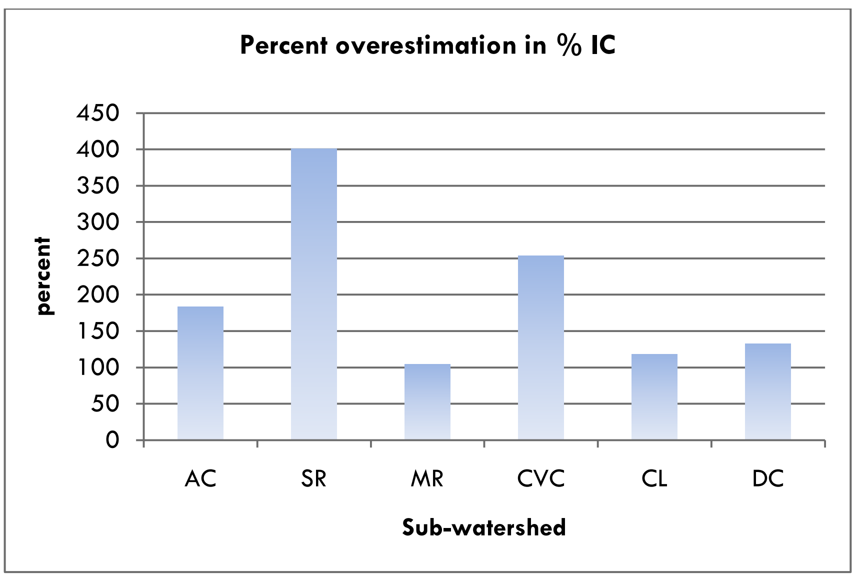


Figure 14. Percent overestimation of impervious cover using ISCs. Another way of viewing the data if Figure 3a is to calculate the percent overestimation that results from calculating impervious cover at a finer scale. For example, in the SR sub-watershed, percent IC in the 100 ft. buffer was 400 percent greater when estimates where made with calculations instead of heads-up digitizing.

This difference is not associated with the resolution of the aerial imagery, but with the method used to develop the ISCs, i.e., the fact that a 9 acre site was digitized to develop coefficients for each land use category. The discrepancy in impervious area confirms that the ISCs should not be applied to small areas; in this case, areas that were 100 feet wide. *Pending further study, we suggest not using the ISCs for sites of less than 2 acres or for a stream buffer that is less than 300 feet wide.* This recommended minimum would account for restrictions of the location of a structure on a parcel, such as when local ordinances or a floodplain might restrict the siting of a house, building, or pavement that would restrict the random distribution of hardscape on a parcel.

Figure 15 illustrates the differences in IC at three different scales (100 and 1000 foot stream buffer and within the entire sub-watershed) in urban vs. rural sub-watersheds in the Dry Creek watershed. This analysis was performed to determine if greater IC was found in riparian buffers in urban sub-watersheds. In fact, the percent IC in the 100-foot buffer was twice as great in urban areas of the watershed, although the overall percent was less than 1 percent in both cases. The urban sub-watersheds have twice the amount of IC in the 1000 foot buffer, 25 percent compared to 12 percent. This relationship is the same for the entire sub-watershed. Probably of greatest interest is the fact that the level of IC in the urbanized sub-watersheds of Dry Creek is quite high, well above the level associated with adverse impacts on stream health (OEHHA, 2008).

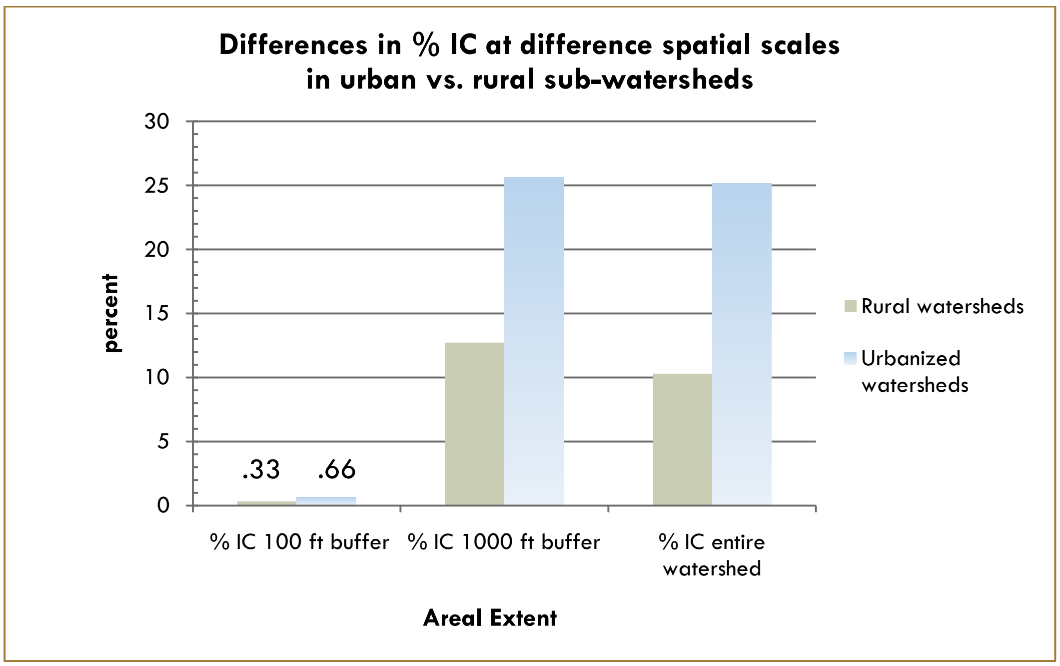


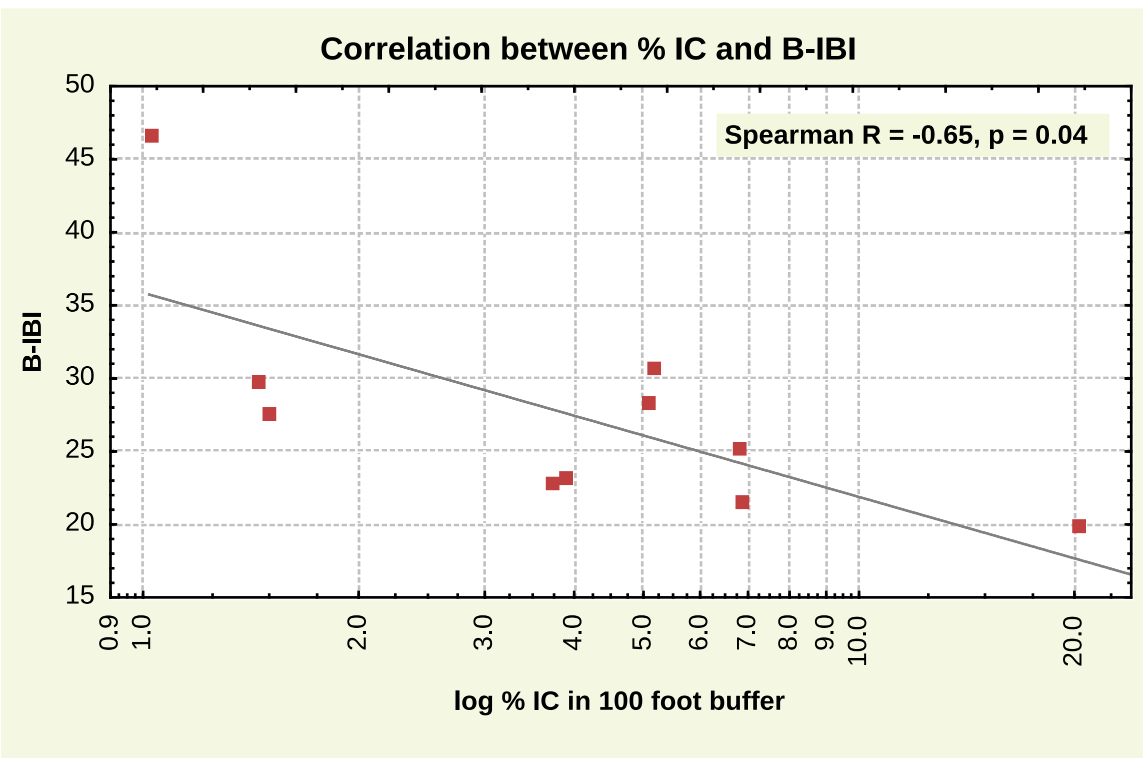
Figure 15. Comparison of % IC at 3 different spatial scales in rural and urbanized watersheds. Bars represent average % IC (n = 4-5) within the defined area.

D. Examples of the Relationship between Impervious Cover and Aquatic Life

Significant efforts have been made to understand the relationship between impervious cover and aquatic life and habitat. In 1995, work by Schueler called attention to this linkage when he identified the general benchmarks of 10 percent and 25 percent impervious cover as indicators of threatened and degraded stream quality respectively. These relationships were established from data on waterways in the eastern United States. In the arid west, these benchmarks do not necessarily hold. Research done by Coleman et al. (2005) suggests that changes in aquatic habitat, specifically stream widening, occurs at imperviousness as low as 2 or 3 percent in southern California.

Relating impervious cover to various benthic macroinvertebrate indices (BMI) can be used as another indicator of potential impacts. Measurement of the abundance and diversity of benthic macroinvertebrates serves as an indicator for all types of stressors, both chemical and physical, over time. Further, because benthic invertebrates share the same riffle habitat as salmonids, these indices can serve as a surrogate for conditions that might impact salmon and steelhead. This is especially useful because factors that impact the population of salmonids can be the result of conditions both in the ocean and in freshwater. In contrast, the aquatic phase of the life of insects is restricted to freshwater. Therefore, BMIs can help to explain the extent to which freshwater habitat might be influencing the health of anadromous fish without the confounding factors of oceanic conditions. This information can help guide watershed management as well as natural resource and land use policy.

One of the most commonly used metrics of aquatic life is the benthic index of biotic integrity (B-IBI). A B-IBI has been developed for Southern/Central California (Ode, Rehn, & May, 2005). This B-IBI is frequently used throughout California, even though the index is based on conditions in the southern part of the state. In addition to the B-IBI, metrics based on the abundance (percent contribution of dominant taxa), diversity (# of taxa), tolerance to perterbation (percent tolerant species) and feeding groups (e.g., percent scrapers) are also commonly used to characterize the population of macroinvertebrates.



In Figure 16 (above) the relationship between impervious cover within a 100 foot buffer around each tributary are correlated with the B-IBI. It appears that imperviousness, a surrogate for disturbance, close to the waterways adversely affects aquatic macroinvertebrate abundance and diversity.

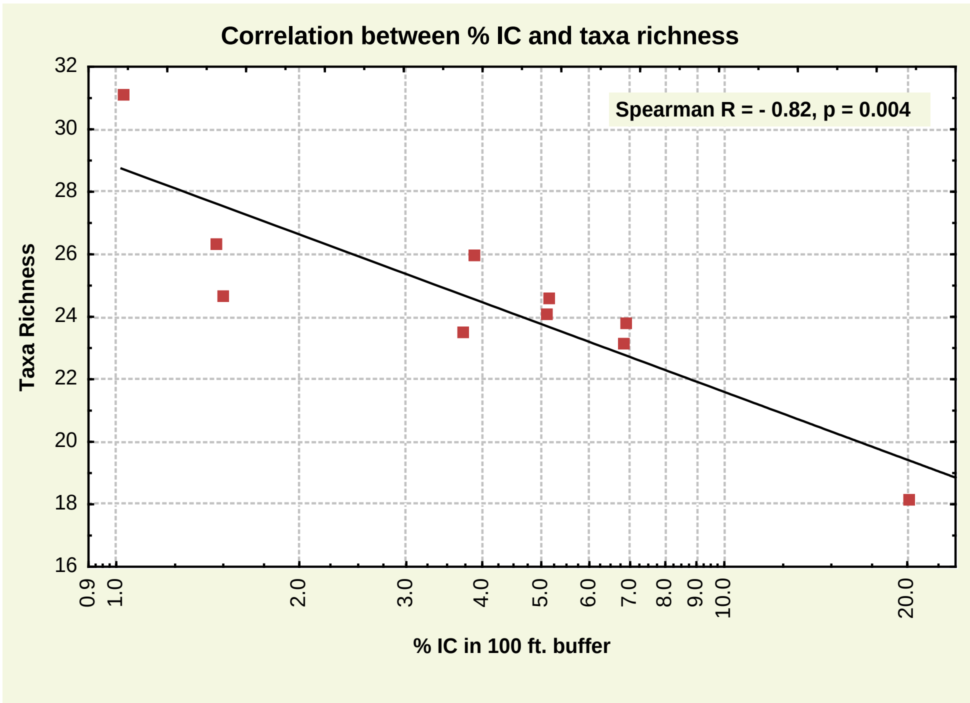


Figure 17. Impervious cover and taxa richness.

Figure 17 (above) illustrates the relationship between imperviousness in the 100 foot buffer and taxa richness, a measure of the diversity of benthic insects, in the Dry Creek watershed. A highly significant negative correlation was identified between these two factors. Data from Figures 5 and 6, as well as other findings, suggest that in the Dry Creek watershed that a 100 foot riparian buffer is inadequate to protect aquatic life. Additional data would be required to validate this hypothesis since the one data point at 20 percent impervious cover has a large influence on the relationship. This relationship might be useful to land use planners since it illustrates the importance of protecting wide streamside buffers to prevent adverse impacts on aquatic habitat and life.

One final example of how the analysis of imperviousness can be used to understand watershed conditions is illustrated in Figure 18 (below). The Shannon Index is a relative measure of species richness and evenness (i.e., the proportional distribution of organisms in the different taxa). Lower values suggest that fewer taxa were counted in the samples collected and that a few taxa accounted for the majority of the sample collected. This index provides a relative comparision of species abundance and distribution at different sites in the watershed. As impervious cover increases in the sub-watershed, abundance and evenness of species falls. One explanation for this and similar findings is that hydromodification, changes in the watershed hydrology associated with greater impervious cover, has altered the habitat for benthic macroinvertebrates, adversely impacting diversity. In the Dry Creek watershed, there is a mix of urban and rural residential development. In rural areas, roadside ditches are used to route stormwater away from homes while other areas have a developed storm drain system that connects impervious cover and drains directly into the local creeks. The mix of land uses is one factor that complicates the analysis of the data. These issues and related factors are discussed further in the chapter on Benthic Macroinvertebrates in the *California Watershed Assessment Manual*, Vol. II (Shilling, 2008).

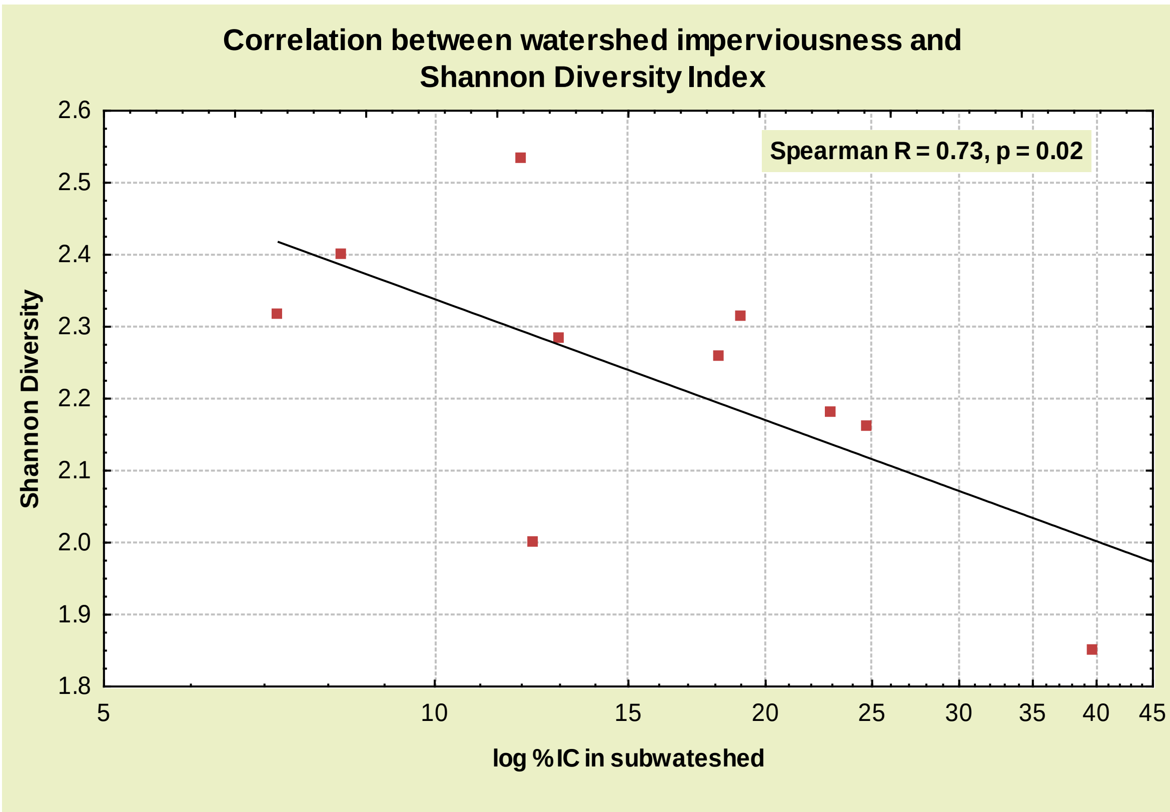


Figure 18. Correlation between impervious cover and Shannon Index.

Overall, percent impervious cover at various spatial scales and similar landscape metrics such as percent developed vs. natural land cover, can be helpful in interpreting metrics of aquatic life. One limitation of the measurement of imperviousness using the ISCs however, is that they do not assess *connected* impervious area, the uninterrupted network of hardscape and pipes. While connected impervious area is the most relevant metric for determining effects on aquatic life and habitat, it can be difficult and time consuming to measure (Sutherland, 1995).

E. Conclusion

Watershed impervious cover serves as a valuable metric for evaluation of the potential effects of hydromodification and urbanization in a watershed. The areal extent of imperviousness and its proximity to waterways influences the degree of impact caused by these alterations. The use of imperviousness as an indicator of habitat quality rests on the assumption that IC is connected, allowing rain that falls on hardscape to flow into the storm drain system and discharge into the local waterway. This is generally the case. However as California advances requirements for stormwater and hydromodification management, including infiltration of stormwater at or near the source, the linkage between IC and stream health might not remain as strong. For the present, however, percent total imperviousness can be used as an indicator of landscape disturbance and a useful metric estimating the degree of alteration or, conversely, the degree to which more natural conditions are likely to exist in the waterway.

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SECTION VI. OVERALL SUMMARY

A set of California specific impervious surface coefficients have been developed; 11 for commercial land uses, a large set for residential land uses, and 3 for roads. They were developed from randomly selected sites in a coastal city, Santa Cruz; an interior valley city, Sacramento, and a Southern California city, Irvine. Sample sizes were determined in order to provide 90% confidence in the values with a 10% degree of precision. These ISC can be used in stormwater management, watershed and natural resources analysis, as well as for land-use planning. To facilitate the use of the ISCs, an Impervious Surface Calculator has been developed which simplifies the calculation of current and future impervious cover.

The California ISCs can be used in the analysis of stormwater runoff and sizing of stormwater management infrastructure as well as in the assessment of watershed health. Hydromodification is an important factor that links stormwater runoff to the health of the aquatic ecosystem. Impervious cover both cuts off sediment sources, increases runoff volume, and is a path for the introduction of toxic chemicals into stormwater. These chemical and physical stressors threaten to further degrade the state's waterways as regions of the state continue to urbanize. Impervious cover within riparian buffers, a surrogate for disturbance, appears to have a particularly strong correlation with adverse effects on aquatic life. The ISCs can be used by local and regional planning agencies as well as the development community to assess the potential impacts of new development projects and identify ways to 'plan with nature in mind'.

Additional information about hydromodification, including an easy-to-read fact sheet and more in-depth technical information, can be found at www.oehha.ca.gov. Click on the Ecotoxicology tab to navigate.

Staff of OEHHA's Ecotoxicology Program are available to answer questions or provide assistance in the use of the impervious surface coefficients.

Table 8: California Impervious Surface Coefficients

Non-Residential Land Uses	
Land Use	**California ISC**
Retail	86
Retail/Office	80
Coastal Development	23
Office Park	69
Urban Office	85
Light Industrial	81
Heavy Industrial	91
Public/Quasi-Public	50
Mixed Use	80
Open Space	2
Agriculture	4
Roads	
Urban/Suburb	91
Rural	43
Highways	47

Residential Land Uses	
Density (du/acre)	**California ISC**
0.5	0.14
1	0.24
2	0.35
3	0.41
4	0.46
5	0.49
6	0.52
7	0.54
8	0.56
9	0.58
10	0.60
11	0.61
12	0.62
13	0.64
14	0.65
15	0.66
20	0.70
25	0.74
30	0.76
35	0.79
40	0.81
45	0.83
50	0.84

Regression equation from which the values were derived:
$Y=0.2449+0.352 \times \log \text{density}$

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