Impervious Surface Coefficients for General Land Use Categories for Application within San Diego County

County of San Diego, Department of Planning and Land Use

Background

A rapid conversion of open or agricultural landscapes to a built environment of urban/suburban features is followed with a commensurate increase in impervious cover. Any surface that water cannot penetrate is considered *impervious*. With increased impervious cover, there is a reduction in the ground's ability to absorb water. This results in greater runoff and the potential for increased erosion and therefore a degradation of aquatic habitat (OEHHA, 2008). Increased runoff also contributes to the transport of pollutant constituents such as oil, pesticides, and nutrients.

Recent water quality and land use literature suggests that, at a watershed scale, the percent impervious cover directly correlates to the overall surface water quality health when that cover exceeds the threshold of 15% impervious (Sleavin, 1999). A University of Connecticut Study further suggests impervious surface thresholds with respect to relative watershed health (Univ. of Connecticut, 1999):

- Where <10% of a watershed is covered with impervious surfaces, aquatic ecosystems are generally protected, although may be stressed.
- Where 11 – 25% of a watershed is covered with impervious surfaces, aquatic ecosystems are likely impacted. Mitigation may be successful.
- Where over 25% of a watershed is covered with impervious surfaces, aquatic ecosystems are most like degraded. Mitigation will be difficult (Figure 1).

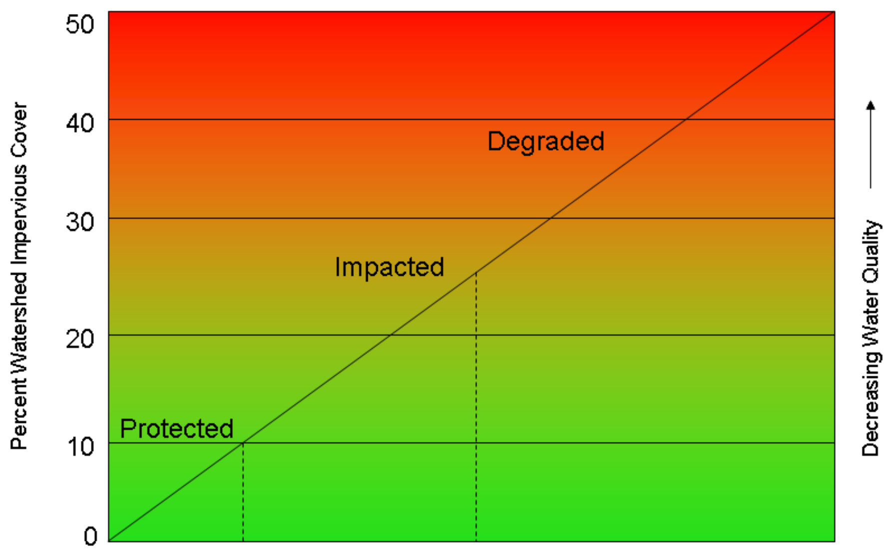


Figure 1. As the impervious surface cover in a watershed increases, water quality decreases.

Impacts to the environment as a result of this conversion of pervious to impervious land cover (IC) can be reduced or avoided. An understanding of the implications of IC with respect to land use planning can be beneficial in reducing imperviousness or its effects by employing appropriate stormwater management practices or identifying alternative development plans that mitigate these effects, such as low impact design techniques (LID) (OEHHA, 2008). Relatively recent literature maintains that ratios of impervious surface cover (commonly referred to as impervious surface coefficients) exist for various types of land use (Wong et al., 1997). These coefficients however were not derived from the local land use information of San Diego County. Building on the efforts of the 2002 pilot study that investigated residential impervious surface fractions in the Upper San Diego River Improvement Area, impervious surface coefficients were developed to estimate the amount of hardscape associated with the general land use categories found in the County of San Diego (County of San Diego DPLU, 2002). The coefficients developed are based on both modeling and *in situ* efforts in the San Diego River Watershed.

Study Area

The San Diego River Watershed is a region of interest and a good location for a study on countywide impervious surface coefficients, because it contains a representative balance of the urban and rural land uses that are found in San Diego County. From dense multi-family, single family residential and commercial land uses in the mid-city area of the City of San Diego to estate residential, agriculture, and open space in its upper reaches, the San Diego River Watershed includes within its boundaries, all of the general land use categories found in the county. The watershed is 434 square miles and includes the cities of Santee, El Cajon, La Mesa, and a portion of the City of San Diego (Figure 2). Additionally, the communities of Julian and Alpine are located within its boundaries. The San Diego River flows through the highly populated area of Mission Valley before it empties into the Pacific Ocean, just south of Mission Bay.

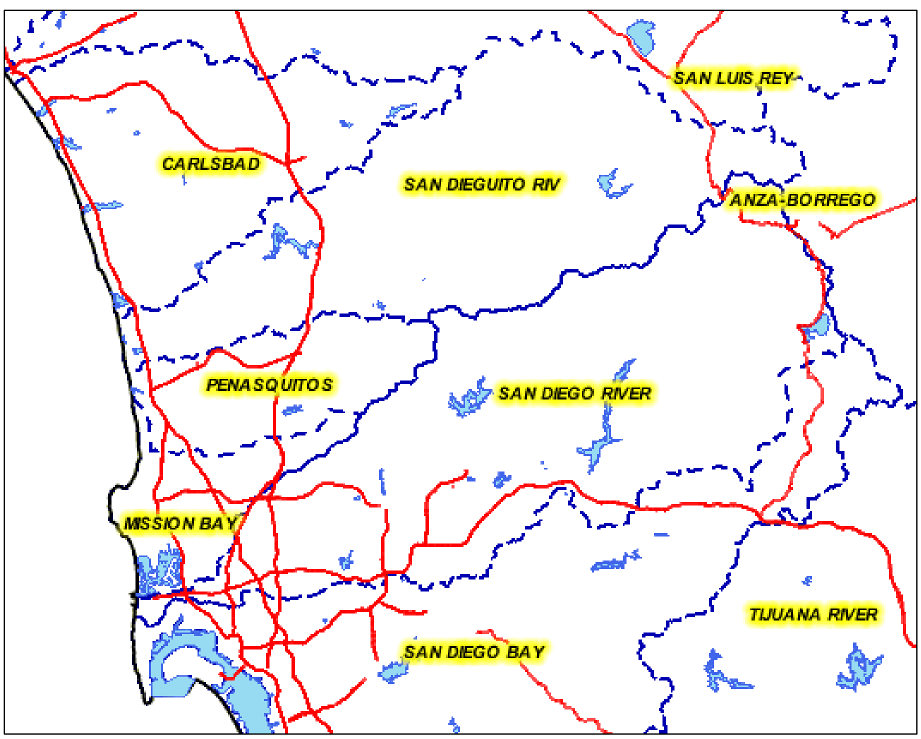


Figure 2. The San Diego River Watershed and surrounding area.

Methodology

High resolution satellite imagery was acquired for several sample areas within the San Diego River Watershed (SDRW). An image processing model was developed whereby impervious surfaces were extracted from the imagery based on user-defined variables. Describe in the literature as hierarchical learning, this modeling technique relies on user feedback to iteratively improve the classifications that are generated. Essentially, the software utilizes interactive learning sessions with the user to detail where the software was correct and where it misclassifies the imagery. Once the variables are established, the model is trained to recognize the features of interest and classifies the image.

Within the study area, five image samples, distributed throughout the watershed and encompassing all general land uses were input to the model. Each of the sample images were classified as either pervious or impervious cover. The output was put into a GIS for further analysis. A ground-truth dataset was created by generating a stratified random sample of over 6,000 points across the study area and classifying the points as either pervious or impervious. This step was accomplished via photo interpretation of current high-resolution vertical and oblique color aerial photography. The ground truth data generated was used to test the accuracy of the model using the Kappa statistic, which is a summary statistic commonly used to compare map products to ground truth data. (Congalten, 1991). The Kappa coefficient is used to describe the agreement between two sets of categorical data that are in discrete classes. The closer Kappa is to 1, the higher the accuracy is of the map product when compared to the ground reference data. Because this study results in two discrete classes (pervious and impervious surface cover) and not a continuous variable, Kappa is an appropriate statistic. In this study, the Kappa was employed to examine the modeled data and the randomly selected validation data. The results of a Kappa statistic range from negative infinity to positive one. A negative Kappa value indicates that a classification performed worse that would be expected by chance. A zero Kappa value indicates that the classification performed as well as a random classification would be expected to perform. A positive Kappa value indicates that the classification performed better than a random classification would be expected to perform.

Once satisfactory model outputs were achieved for each of the sample images, the impervious surface coefficient was calculated by dividing the impervious area generated by the model by the total area for a given land use cover.

Residential Land Uses

Because residential uses vary dramatically within the SDRW and across the County of San Diego, a different approach was used to determine impervious surface coefficients for residential areas. In the 2002 pilot study and again in the current study, impervious surfaces were underestimated using the image processing approach described above. A study conducted by the California Office of Environmental Health Hazard Assessment suggests that there is a relationship between density and impervious surface fraction for residential land use categories in any community in California (OEHHA, 2008). The authors adopted an approach that treats density, the number of dwelling units/acre, as a continuous variable and determined a regression equation that describes the relationship between density and impervious surface fraction for residential land use categories.

$$ISC = -0.2304 + .4961 * X^{0.2196}$$

Where X = residential density (du/acre)

Modeling Results: Non-Residential Land Use

Overall accuracy for the impervious surface modeling computed by dividing the total correct (sum of the major diagonal) by the total count in the error matrix was 84%. Assessment of the user's accuracy or reliability (the probability that a feature classified in the model actually represents that category on the ground) for both categories is also described in the table. User's accuracies were found to be 83% and 84% for pervious and impervious classifications respectively. The classification product, as seen in

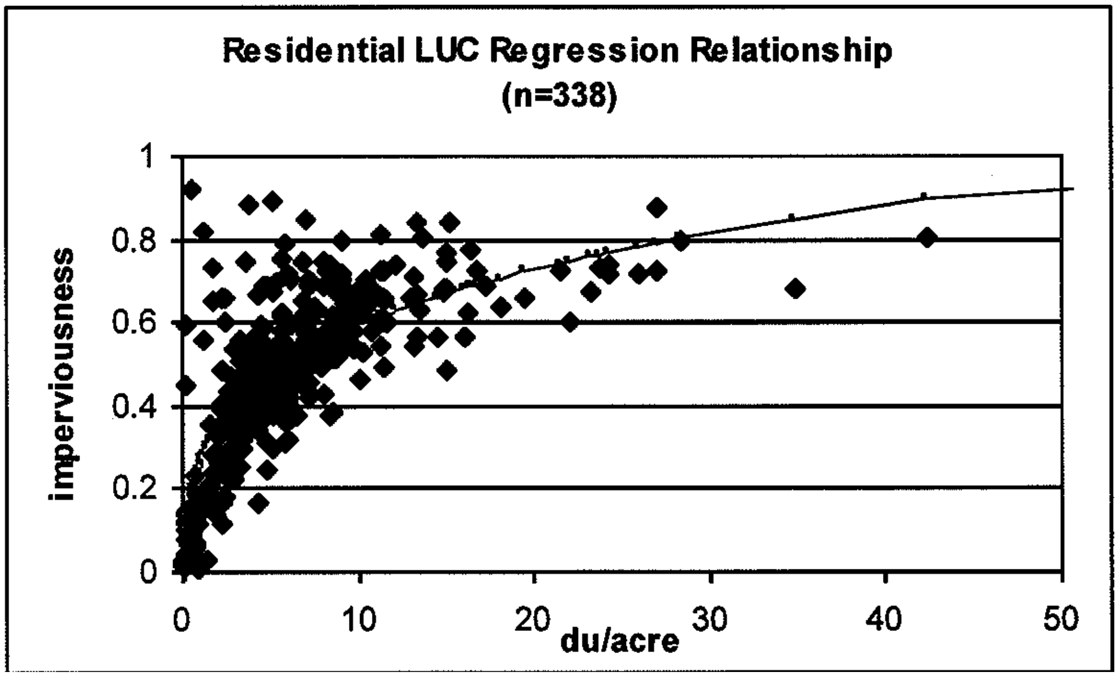
Figure 3, had a Kappa of .660 when compared to reference data, which is generally good agreement. Results for the non-residential land use classification could be further improved by adding a texture layer to the model input, such as the black and white 1 – meter satellite imagery. The addition of a texture layer will allow the model to better differentiate between linear and non-linear features.

ERROR MATRIX			
	REFERENCE DATA		
CLASSIFICATION	PERVIOUS	IMPERVIOUS	ROW TOTAL
PERVIOUS	1011	206	1217
IMPERVIOUS	328	1764	2092
COLUMN TOTAL	1339	1970	3309
OVERALL ACCURACY = 2775/3309 = 84%			
Producer's Accuracy (Measure of Omission Error)			
Pervious = 1011/1339 =	76%	24% Omision Error	
Impervious = 1764/1970 =	90%	10% Omission Error	
User's Accuracy (Measure of Comssion Error)			
Pervious = 1011/1217 =	83%	17% Comission Error	
Impervious = 1764/2092 =	84%	16% Comission Error	
K_{hat} =	66.01%		

Figure 3. Impervious Surface Classification Error Matrix

Results: Residential Land Use

Figure 4 illustrates the regression relationship between dwelling units/acre (density) and impervious surface fraction. The OEHHA study determined that a relationship between these two variables exists with a R^2 of 0.5930 (2008). Comparisons to our ground truth dataset developed using very high resolution aerial photography supports the relationship. In this study the equation developed in the OEHHA study was applied to residential densities in the SDRW to determine impervious surface fraction. The fractions were averaged over the general residential land use categories found in the County of San Diego to determine the land use based impervious surface coefficients.



SOURCE: *Impervious Surface Coefficients: A tool for environmental analysis and management. OEHHA 2008. pg. 2.*

Figure 4. Residential LUC Regression Relationship

Results: San Diego River Watershed

The SDRW is 277,540 acres. Of that, 49, 457 acres is under an impervious land cover, resulting in an impervious surface fraction of 17.82%. According to the University of Connecticut study the SDRW is impacted (Figure 1), with mitigation measures potentially successful (1999). Figure 5 shows a map of the impervious surface fractions determined by applying the impervious surface coefficients that were derived using the techniques described previously, to the area of each land use cover found in the watershed. A more detailed description of calculating impervious surface fraction is discussed in the next section. The downstream portions of the watershed have the majority of the impervious surfaces. The upper basin has many continuously pervious areas with some sub-basins almost completely pervious.

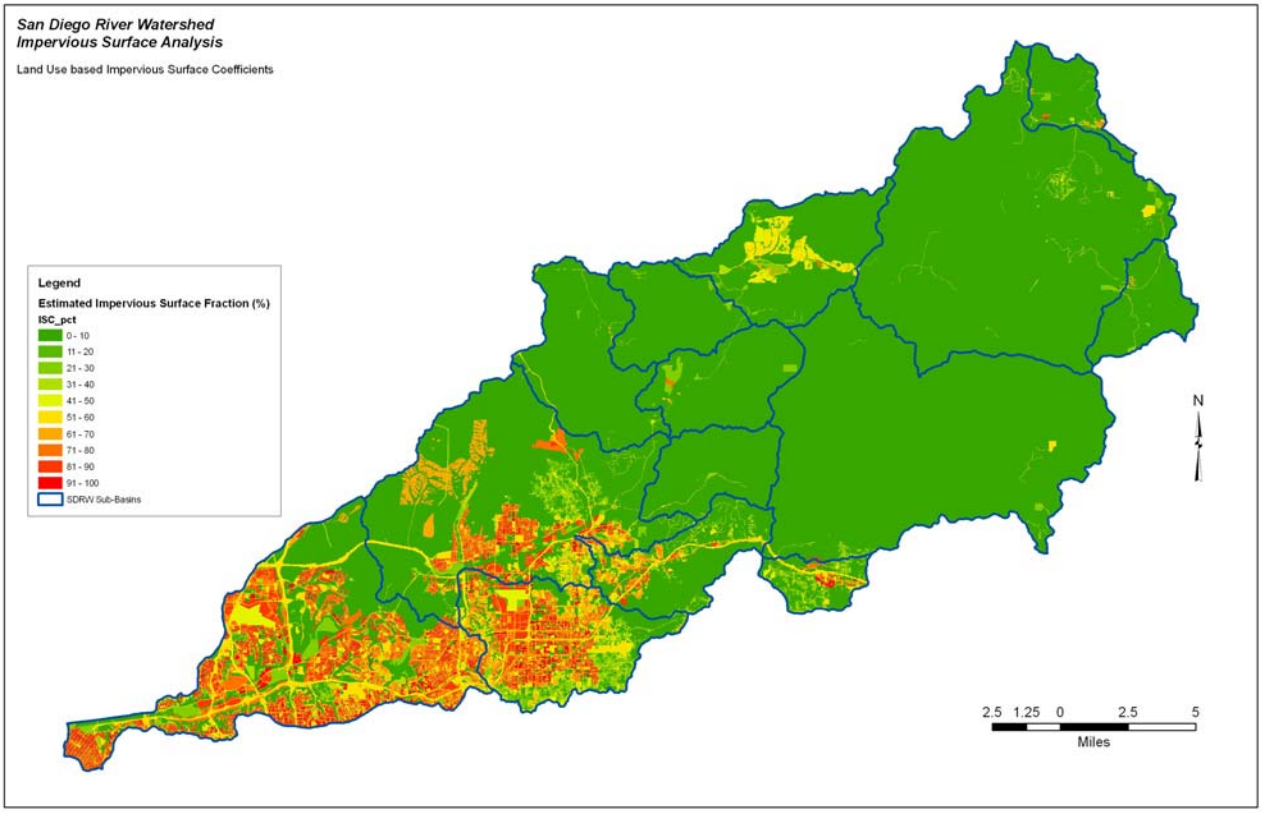


Figure 5. SDRW Impervious Surface Coefficients

Future Applications of ISC in San Diego County

Calculating Current Impervious Surface Fraction

Calculating the current impervious surface fraction for all watersheds in the County of San Diego can be accomplished by applying the estimated ISCs to the land use classifications.

$$Impervious\ Area = Area * ISC$$

Calculate total impervious surface fraction by summing all impervious surface area in all land use categories and dividing it by the total area in the study area (i.e. watershed, community plan area).

$$Impervious\ Fraction = Impervious\ Area / Total\ area$$

General Plan Update Build-Out Analysis

An impervious surface build-out analysis using densities specified in the GP Update draft land use data can be accomplished by adding the number of acres for each land use category that is both planned and existing. Multiply these total acreages by the appropriate ISC. Sum the number of impervious acres for each land use category to get the total impervious surface area.

Conclusion

The impervious surface coefficients developed will facilitate the calculation of impervious surface fraction in other watersheds in the County of San Diego. Because the coefficients were derived from a study area that incorporates a representative sample of land use categories found in the county makes the coefficients appropriate for application in other watersheds in the county. There is high confidence in the coefficients because they were developed by applying well tested feature extraction modeling techniques to high resolution multi-spectral satellite imagery.

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APPENDIX A: Impervious Surface Coefficients for Non-Residential Land Use Categories and for Aggregated Land Use Categories.

Aggregated Land Uses	ISC
Airports	0.4517
Commercial Recreation	0.2136
Commercial and Office	0.7075
Communication-Utilities	0.3976
Education	0.5559
Extensive Agriculture	0.0840
Extractive Industry	0.7293
Freeway-Roads	0.5903
Heavy Industry	0.7994
Institutions	0.5597
Intensive Agriculture	0.0643
Light Industry	0.8190
Military	0.6103
Parks	0.0555
Shopping Centers	0.8750
Transportation, Communication, Utilities	0.6335
Undeveloped	0.0796
Water	0.0719

LAND USE (All Categories)	ISC
AIRSTRIPS	0.7649
AUTOMOBILE DEALERSHIPS	0.8835
CASINOS	0.9232
CEMETERY	0.4395
COMMERCIAL UNDER CONSTRUCTION	0.6774
COMMUNICATIONS AND UTILITIES	0.3976
COMMUNITY SHOPPING CENTERS	0.8278
CONVENTION CENTER	0.6631
DORMITORIES	0.4839
ELEMENTARY SCHOOLS	0.5549
EXTRACTIVE INDUSTRY	0.7293
FIELD CROPS	0.0840

FIRE/POLICE STATIONS	0.6269
FREEWAYS	0.5711
GENERAL AVIATION AIRPORTS	0.4470
GOLF COURSE CLUBHOUSES	0.5152
GOLF COURSES	0.0421
GOV'T OFFICE/CIVIC CENTERS	0.7971
HEAVY INDUSTRY	0.7994
HOSPITALS-GENERAL	0.7372
HOTEL/MOTEL (HI-RISE)	0.7131
HOTEL/MOTEL (LO-RISE)	0.4922
INDUSTRIAL PARKS	0.8112
INTENSIVE AGRICULTURE	0.1122
JUNIOR HIGH SCHOOLS AND MIDDLE SCHOOLS	0.5473
JUNKYARD/DUMP/LANDFILL	0.6185
LAKES, RESERVOIRS, LARGE PONDS	0.0719
LANDSCAPE OPEN SPACE	0.2023
LIBRARIES	0.5696
LIGHT INDUSTRY-GENERAL	0.8307
MILITARY USE	0.6103
MISSIONS	0.0483
MOBILE HOME PARKS	0.7377
MONASTERY	0.1687
NEIGHBORHOOD SHOPPING CENTERS	0.8408
OFFICE-high rise	0.6026
OFFICE-low rise	0.6439
OPEN SPACE RESERVES, PRESERVES	0.0555
ORCHARDS AND VINEYARDS	0.0257
OTHER GROUP QUARTERS FACILITIES	0.4617
OTHER HEALTH CARE	0.6793
OTHER PUBLIC SERVICES	0.5557
OTHER RECREATION	0.3309
OTHER RETAIL TRADE AND STRIP COMMERCIAL	0.7998
OTHER SCHOOLS	0.5025
OTHER TRANSPORTATION	0.5474
OTHER UNIVERSITIES AND COLLEGES	0.5335
PARK AND RIDE LOTS	0.8694
PARKING LOTS -STRUCTURE	0.6031
PARKING LOTS -SURFACE	0.7438
PARKS - ACTIVE	0.1387
POST OFFICES	0.7751
RACETRACKS	0.6448
RAIL STATION/TRANSIT CENTERS	0.7652
RAILROAD RIGHT OF WAYS	0.5124
REGIONAL SHOPPING CENTERS	0.9351
RELIGIOUS FACILITIES	0.4781
RESIDENTIAL RECREATION	0.1783
RESIDENTIAL UNDER CONSTRUCTION	0.1908

RESORT	0.5880
ROAD RIGHT OF WAYS	0.5975
SCHOOL DISTRICT OFFICES	0.7184
SDSU, SMSU, UCSD	0.5243
SENIOR HIGH SCHOOLS	0.5522
STADIUMS/ARENAS	0.9251
STORE-FRONT COMMERCIAL	0.8308
UCSD, VA HOSPITALS, BALBOA HOSPITAL	0.5283
WAREHOUSING & PUBLIC STORAGE	0.8338
WHOLESALE TRADE	0.8422