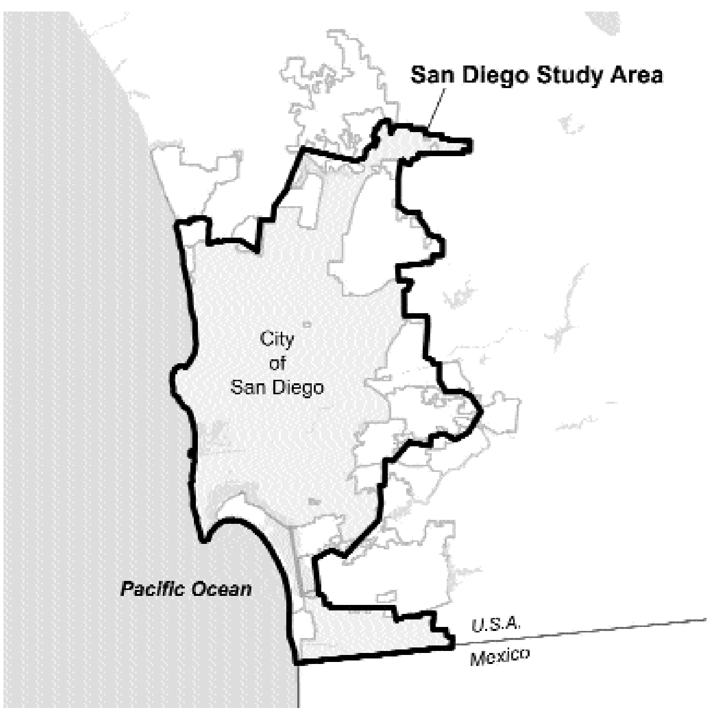
July 2003

Urban Ecosystem Analysis San Diego, California

Calculating the Value of Nature

Report Contents



Project Overview

AMERICAN FORESTS, with the support and cooperation of the city of San Diego, State of California, the USDA Forest Service and others, analyzed the effects of 17 years of changing landcover in San Diego, California. This study created a "green data layer" —a high resolution digital map that fits into infrastructure data currently managed by the city's Geographic Information Systems (GIS). The analysis of the changing land cover provides public policy makers with a clear picture of the historic effect of the city's land use policies. The data layer provides leaders with an accurate picture of existing land cover and the capacity to include the benefits of trees and other land cover in their decision-making process.

In this report, AMERICAN FORESTS provides the city of San Diego with a technical analysis of satellite imagery to document the impact of land cover on the costs of managing air and water resources. This study marks the beginning of a new era for the management of the city's urban forests. Along with the findings in this report, the city will receive new data giving decision makers valuable information about its green infrastructure—its trees and other vegetation.

The analysis of the study area using Landsat satellite imagery covered 319,000 acres (499 square miles), including the city of San Diego (218,000 acres), 11 other complete communities or cities (Bostonia, Coronado, Del Mar, El Cajon, Imperial Beach, La Mesa, Lemon Grove, National City, Poway, Santee, and Solana Beach) and portions of 11 additional communities or cities (Bonita, Casa De Oro-Mount Helix, Chula Vista, Encinitas, Escondido, Fairbanks Ranch, Granite Hills, La Presa, Rancho San Diego, and Spring Valley.

In addition to a temporal (time sequence) analysis of the changing landcover using Landsat satellite imagery, a detailed assessment of the city's tree cover was also conducted using high-resolution multispectral satellite imagery to produce a digital green data layer. The analysis uses this land cover database to run ecological models which articulate the effect of the land on air and water. Scientific and engineering models have been programmed into CITYgreen® computer software and are used with GIS technology to calculate the data.

In response to the policy direction in the city's Progress Guide and General Plan, the city of San Diego has phased urban development over the last 25 years, while requiring new infrastructure commensurate with the new development. Today, the city has almost reached its current plan build-out, yet growth pressure remains strong. Recent San Diego Association of Governments (SANDAG) projections show a 284,000 increase in population between 2000 and 2020, with less than 10% of the city's vacant and developable land remaining. The challenge to balance environmental quality and development needs will require the city to be more innovative and effective in planning land use.

Many quality of life issues are directly related to the environmental benefits of trees. Sixty percent of San Diego County's air pollution is vehicular related. The city has been classified as a "serious non-attainment area for ozone" by both the state and federal government. The city could lose federal funding for roads and highways because of its non-attainment status for ozone. Improving air quality will require work on many fronts including greening the metropolitan area's landscape. Research shows that increasing tree cover reduces air pollution—details on San Diego's community forest are provided in this study. Since the rolling black outs of 2001, energy conservation is on Californian's minds and the need to decrease the demand for energy from fossil fuel power generating facilities is a priority. Trees' ability to shade buildings plays a role in reducing energy need. Saving energy also means reducing air pollution and cooling the urban heat island.

Many other quality of life issues are directly related to the tree cover, as well. The digital green data layer given to the city as part of this project will also provide information needed to assess stormwater runoff that pollutes the city's beaches and bays. Non-point water pollution occurs when rain and excess irrigation water pick up oils and other urban contaminants from roadways and yards and deposit them into the city's waterways. Pollution warnings are frequently posted at the beaches after rain events. The problem is exacerbated with new development that creates additional impervious surfaces. Not only does this contribute more pollutants, but it also reduces the land's natural ability to filter and infiltrate the runoff as it makes its way through the city to the bays and ocean.

San Diego's climate, vegetation, and geography pose some unique challenges to tackling these urban issues. The region receives only 9-11 inches of annual rainfall, sometimes as little as 4 inches in a dry year. Ninety percent of water is imported, so water conservation and reuse is a necessity. While not intuitive, trees actually conserve water by shading buildings and reducing the need for air conditioning, which uses more water than trees. They also shade lower levels of vegetation and non-native landscapes that typically transpire greater levels of water in full sun instead of under tree canopy. The native vegetation of this area is typically coastal sage scrub and chaparral which are found on the mesa tops and sides of hills. Riparian woodlands, primarily native California oaks and sycamores, are found in the bottom of the valleys. Naturalized woodland species include eucalyptus and pepper trees. While urban and suburban development has replaced scrub and chaparral with tree cover, it is important to increase tree cover to offset the environmental impacts created over the last 25 years as natural areas have been urbanized.

Conserving and fostering a healthy green infrastructure is more than an aesthetic choice, it's an environmental and economic one. Employing tree conservation and forest restoration as a tool to help clean the air and water can save the city millions of dollars in managing air and water issues while improving the quality of life for its residents. With this analysis and data, planners and decision makers can put a value on their trees and project the benefits of increased tree cover in land use plans. AMERICAN FORESTS provides the city with a digital green data layer for its GIS along with CITYgreen software and training as part of this project.

Major Findings for San Diego

AMERICAN FORESTS used Landsat TM imagery (30-meter resolution) as well as high-resolution (4-meter multispectral) satellite imagery as a data source for this project. From this data set, GIS analysts calculated stormwater runoff and air quality benefits of the tree cover in the city of San Diego and in portions of surrounding communities using nationally recognized scientific and engineering models. While this study presents findings for the city as a whole, the city's eight council districts and 52 community planning areas, and 11 surrounding communities, the same data can be used to analyze specific issues.

Over the past two decades, the city of San Diego and the entire study area lost green infrastructure.

■ Using Landsat imagery analysis, the city of San Diego is comprised of 110,044 acres of urban land (51%), 48,674 acres of grassland (22%), 32,956 acres of shrub land (15%), and 14,738 acres of tree canopy (7%).Water, wetlands, sand, and bare (agricultural/fallow) land comprise 5% of the total area and are considered too small to be a factor in the calculations of this study.

■ Between 1985 and 2002, the city of San Diego lost 32% of its grassland, 27% of its tree cover, and 7% of its shrub land. Over that same time period, the city's urban areas increased by 39%.

The loss of tree cover impacts the ability of the area's urban forest to provide its potential benefits affecting air, stormwater, and carbon.

■ As of 2002, the total stormwater retention capacity of the city of San Diego's urban forest was 82 million cubic feet. Without these trees, the cost of building the infrastructure to handle the increase in stormwater runoff would be approximately $164 million (based on national estimate of construction costs at $2 per cubic foot).

■ Urban forests provide air quality benefits by removing nitrogen dioxide, sulfur dioxide, carbon monoxide, ozone, and particulate matter of 10 microns or less. The city of San Diego's urban forest removes 4.2 million pounds of pollutants from the air each year—a benefit worth $10.8 million annually.

■ Trees' ability to absorb atmospheric carbon reduces greenhouse gases, which are thought to contribute to global warming. The city of San Diego's trees sequester about 9,000 tons per year and store a total of 1.2 million tons.

As a result of a high-resolution imagery analysis, a "green data layer" is ready for San Diego to incorporate into its infrastructure

■ Using a high-resolution imagery analysis from 2002, the city of San Diego is comprised of 85,099 acres of impervious surface (39%), 65,524 acres of grassland (30%), 27,297 acres of tree canopy (13%), and 21,249 acres of shrub land (10%).

■ This data can be used to help set tree canopy goals, calculate the environmental benefits of trees, test new strategies for increasing tree cover, and promote public understanding and stewardship of green infrastructure.

Landcover Change Trends Using Landsat Satellite Data*

	City of San Diego				Entire Study Area			
	1985 acres	**2002 acres**	**2002 Percent**	**% change 1985-2002**	**1985 acres**	**2002 acres**	**2002 Percent**	**% change 1985-2002**
Urban	79,067	110,044	51%	39	110,057	155,156	49%	41
Grassland	71,988	48,674	22%	-32	104,811	72,142	23%	-31
Shrubland	35,565	32,956	15%	-7	53,524	49,392	16%	-8
Tree Cover	20,094	14,738	7%	-27	30,078	21,518	7%	-29
Other**	10,827	11,151	5%	0	20,893	21,165	7%	0
Total	217,542	217,564	100%	0	319,362	319,374	100%	0

**Note: The entire study area includes the city of San Diego and portions of 22 communities and cities. Land cover changes were analyzed using Landsat satellite imagery; ecological benefits were calculated from analysis of high-resolution satellite imagery (see page 10-11).*

***Together water, wetlands, agricultural/fallow land, and sand comprise less than 7% of the area and are not significant for the scale of this study.*

Creating a Green Data Layer

This study produced a rich data set describing the environment. The data coupled with its relevance and accessibility to those working at the local level, offers the opportunity for better land use and development decisions than in the past. This data is an important new resource for those working to build better communities—ones that are more livable, produce fewer pollutants, and are more cost effective to operate.

The data collected is unique because it contains both green infrastructure (areas covered with trees, shrubs, and grass) and gray infrastructure (areas covered by buildings, roads, utilities, and parking lots). While municipalities commonly use geographic information systems (GIS) to map and analyze their gray infrastructure, they typically do not integrate trees and other elements of the green infrastructure into their day-to-day planning and decision-making processes. Reasons for this include: 1) inability to readily calculate the tree cover, 2) inability to quantify economic values of trees and other environmental features, and 3) the absence of a means to readily use this information in commonly used GIS systems.

This study addresses all of these impediments. Data documenting the environmental characteristics of trees is now available thanks to research from the U.S. Forest Service and the Natural Resources Conservation Service. This report describes how an accurate green data layer can be produced for a community's GIS systems. Today we have a clear understanding of the active role trees play improving our urban environment. Those working in planning, urban forestry and related natural resource issues can now readily calculate the dollar value of these ecological benefits in their communities using CITYgreen software and this data.

Adding a green infrastructure data layer to the decision making process introduces a new dimension to planning and development discussions, one that considers how to better integrate green and gray infrastructure to manage air, and water systems. By developing and using a green data layer, future decisions will include better information about the full range of community resources.

The first step in creating a green data layer for use in GIS is to acquire landcover data from satellites or specially equipped airplanes. The data is acquired during the growing season, when the leaves are on the trees. Specialists classify the images into useable data. They categorize the detailed characteristics of reflected light (spectral analysis) and surface structures (spatial analysis) to determine different landcover types—areas covered in trees, grass, or shrub can be distinguished from parking lots, building and roads. This analysis produces a green data layer that can be added to the gray infrastructure that is commonly used in GIS for local planning.

Adding a green data layer to a community's infrastructure pays big dividends. Trees reduce pollution and erosion from stormwater by slowing it and by reducing its peak flow, and they improve air quality by filtering pollutants from the air. The stormwater control value of an area's trees, for example, can be calculated using the green data layer. Research has shown that the greater the canopy coverage and the less impervious surface, the more environmental benefits result. Communities can then devise strategies to increase tree cover and recognize their environmental benefits and management cost savings.

A planimetric map shows a neighborhood's gray infrastructure including buildings and roads (left). Classified high-resolution satellite imagery adds a green data layer (right), with its associated environmental benefits, to use in planning decisions.

Tree Canopy Trends from Landsat

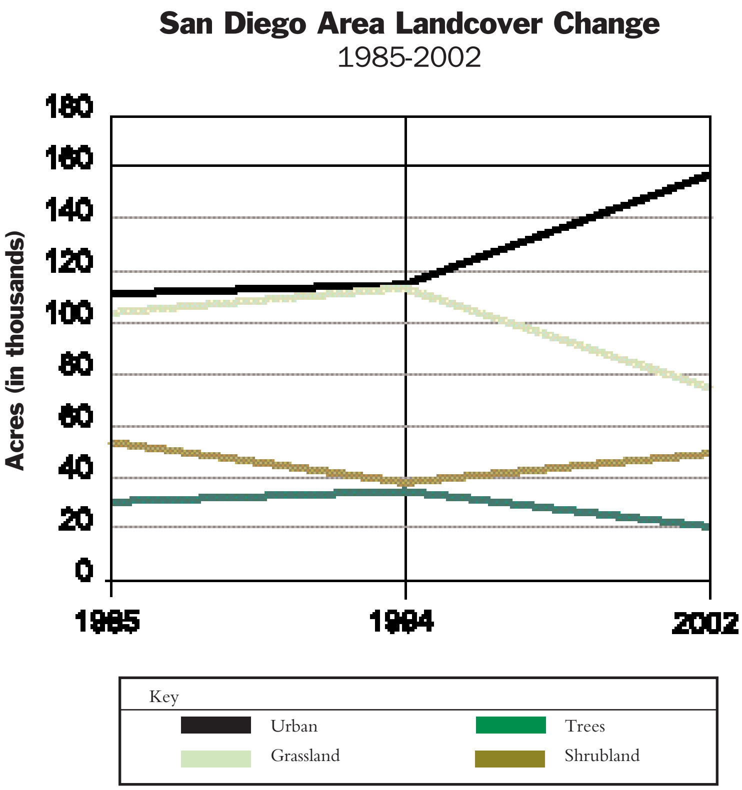
The classified Landsat images above illustrate landcover change in the city of San Diego and surrounding communities between 1985 (left) and 2002 (right).

Landsat satellites have been in orbit around the Earth since 1972 and data from them allow us to look at changes in landcover over time. AMERICAN FORESTS classified Landsat TM satellite images to show the change in different land covers for the city of San Diego and portions of surrounding communities over an 17-year period, between 1985 and 2002. The trends show that natural areas of grasslands, shrublands, and trees have been converted to development during this time.

The Landsat images (above) provide valuable public policy information showing general trends in the changing landcover including tree loss, but do not provide high-resolution data needed for local planning and management activities. High-resolution imagery (like that which is used in this study) produces a 4-meter or better resolution (compared to 30 meter with Landsat) and can be used to accurately inventory the tree cover in San Diego (see pages 8-9).

Graphing Change

The change in vegetation depicted in the satellite images on page 5 is represented in a line graph below. The graph shows the change in landcover over an 17-year period for four categories. Data from three dates were analyzed and the graph shows an increase in the rate of development and tree loss between 1994 and 2002. Urban areas (black) dramatically increased as grasslands (light green) dramatically decreased during the same time period. The graph also shows the decline in tree cover (dark green) and shrubland (olive) that is primarily chaparral and scrub.



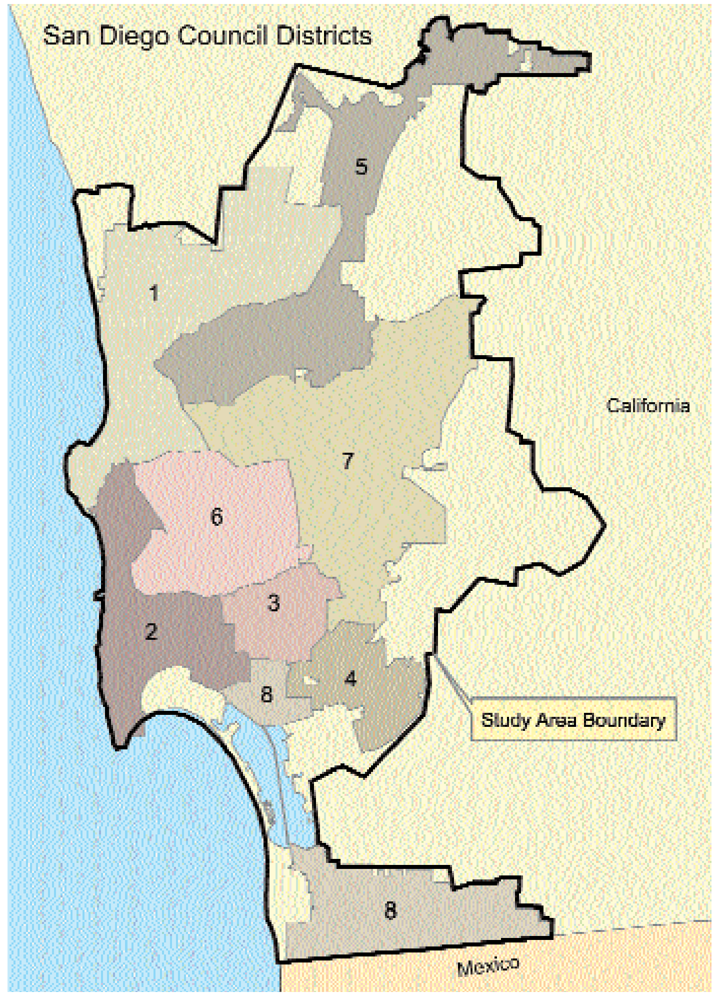
Courtesy of the City of San Diego.

Building a Green Data Layer

More than Meets the Eye

At first glance many of the images in this report appear to be high-resolution photographs. They really aren't. These images have been digitally assembled from large amounts of spatial and spectral data tied to various land characteristics. The images represent far more than the colors seen here; they contain a wealth of data from which tree cover and its benefits can be analyzed. With Landsat imagery, only clusters of trees can be seen; with high-resolution imagery, individual trees can be distinguished. Since the resolution of the imagery is higher and more trees are visible, the calculated values of the green infrastructure will be greater.

Communities can use this data, along with CITYgreen software, to evaluate the environmental benefits and impacts of various growth, development, or management scenarios, including the benefits of strategic tree planting and maintenance programs. The data layer can be subdivided to fit any political or natural boundary of interest within the study area. Each scale of analysis can address different local issues. In addition to the city of San Diego, a complete green data layer is included for 11 other communities/cities within the study area—Bostonia, Coronado, Del Mar, El Cajon, Imperial Beach, La Mesa, Lemon Grove, National City, Poway, Santee, and Solana Beach. Data and an analysis report for each community are available (see sample on page 16).



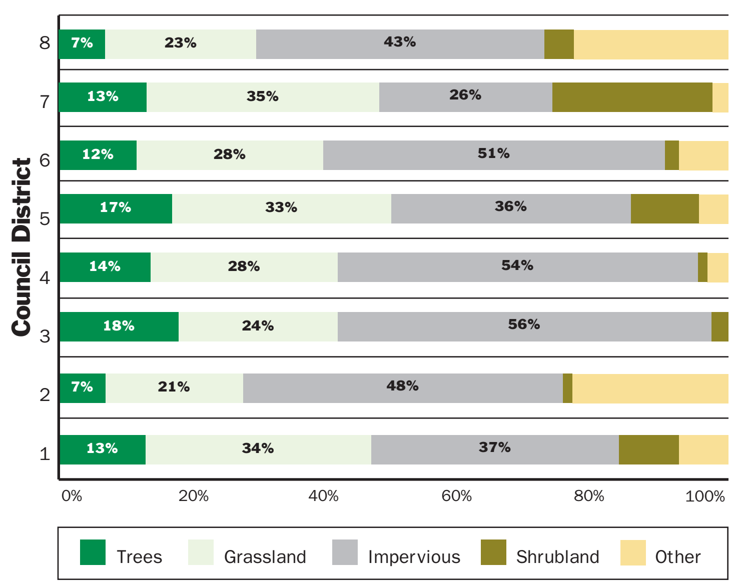
Citywide Scale

The City of San Diego's ten goals include improving air and water quality and managing stormwater runoff to comply with state and federal clean air and water requirements. Cities spend tremendous amounts of money installing and maintaining stormwater management systems. If San Diego cannot meet EPA attainment levels for air and water quality it could jeopardize federal funding for capital improvements. Trees provide a cost effective, non-engineered infrastructure that can help tackle these problems.

Council District Scale

Individual Council members must address both citywide issues and district-specific concerns that affect quality of life for their constituents. Council members can use a green data layer to integrate trees and other vegetation into community planning, brownfields, stormwater projects, traffic calming and other measures, thus improving the city's overall environmental quality as well as aesthetics.

Landcover by Council District



Environmental Benefits of Trees by City of San Diego Council District

Council District	Acres	% Trees	% Shrub	% Impervious	% Grass	Air Pollution Removed Annually (pounds)	Air Pollution Value (Annually)	Retention Volume Required to Mitigate Loss of Trees cu. ft. (2-yr, 24-hr storm)	Stormwater Control Value (One-time Value)	Carbon stored (Total Tons)	Carbon Sequestered (Tons Annually)
District 1	40,777	13	9	37	34	848,043	$2,146,418	12,012,409	$24,024,818	233,664	1,819
District 2	21,269	7	1	48	21	217,830	$551,333	9,618,111	$19,236,222	60,019	467
District 3	9,286	18	2	56	24	263,762	$667,588	4,029,307	$8,058,614	72,675	566
District 4	11,468	14	1	54	28	259,366	$656,462	4,540,382	$9,080,764	71,464	556
District 5	37,931	17	10	36	33	980,637	$2,482,015	21,537,015	$43,074,030	270,198	2,104
District 6	23,261	12	2	51	28	419,652	$1,062,150	9,197,288	$18,394,576	115,628	900
District 7	49,043	13	24	26	35	1,004,535	$2,542,504	10,472,581	$20,945,162	276,783	2,155
District 8	24,537	7	4	43	23	269,195	$681,339	10,346,021	$20,692,042	74,172	577
Total **	**217,572**	**13%**	**10%**	**39%**	**30%**	**4.2 million**	**$10.8 million**	**82 million**	**$164 million**	**1.2 million**	**9,144**

**Note: The council districts include additional military, park, and preserve land not included in the community planning areas. Water, wetlands, agriculture/fallow land, and sand acreages are not included in this table.*

*** Landcover percentages are higher using high-resolution imagery than using Landsat imagery, since the resolution of the imagery is better and more trees are visible. Numbers may differ slightly due to rounding to the nearest whole number.*

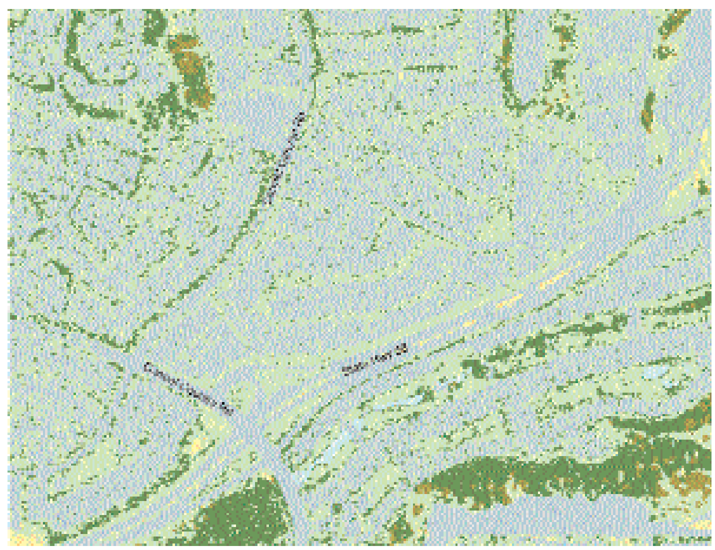
Community Planning Area Scale

When the data is considered at the community scale, tree canopy goals, specific to different land uses (see page 17) can be set along with other land use goals. City governments can use this information to establish priorities and achieve the most impact in light of available funding. Using the green data layer in combination with the existing gray data layers makes this planning easier. It also shows the importance of trees as a community asset. Local ordinances can create mechanisms to ensure that canopy goals are set and achieved. See page 9 for the environmental benefits of trees for the city of San Diego's community planning areas.

Ecological Boundaries

Most environmental issues such as stormwater runoff, water and air quality, and wildlife habitat are not contained within political boundaries. The green data layer can be analyzed using ecological boundaries and can form the basis for more effective regional cooperation.

An effective approach to tackling natural resource issues is to identify ecological boundaries and set tree cover goals for naturally-occurring land features. For example, the City's Multiple Species Conservation Preserve (MSCP) can be used with the green data layer to assist with the program's goals of conserving land as a network of habitat and open space, protecting biodiversity and enhancing the region's quality of life. The preserve will protect habitat for over 1,000 plant species including trees and more than 380 species of fauna.



Carmel Valley began developing from a rural to urban area in the early 1980s. Since 1989, installing one canopy tree in front of each home and one canopy tree for every 30 linear feet of street frontage has been required under new landscape regulations. An analysis of 495 acres within Carmel Valley shows that as of 2002, tree cover provides $352,000 in stormwater management services, removes 9,494 lbs. of air pollutants valued at $24,030 annually, and stores 2,616 tons and sequesters 20 tons/year of atmospheric carbon. Some property owners have removed some of these recently planted trees. As growth and development occur, even additional trees are needed to mitigate the negative impacts on air quality and stormwater.

Environmental Benefits of Trees by City of San Diego Community Planning Area

Community	Acres	% Trees	% Shrub	% Impervious	% Grass	Air Pollution Removed Annually (pounds)	Air Pollution Value (Annually)	Retention Volume Required to Mitigate Loss of Trees cu. ft. (2-yr, 24-hr storm)	Stormwater Control Value (One-time Value)	Carbon stored (Total Tons)	Carbon Sequestered (Tons Annually)
Balboa Park	1,304	22	4	32	41	45,585	115,377	404,008	$808,016	12,560	98
Barrio Logan	551	2	0	87	10	1,812	4,587	0	$0	499	3.89
Black Mountain Ranch	5,040	5	4	26	52	40,758	103,160	2,397,799	$4,795,598	11,230	87
Carmel Mountain Ranch	1,516	17	1	52	30	39,507	99,992	1,076,829	$2,153,658	10,885	85
Carmel Valley	4,537	13	9	48	29	94,772	239,869	1,558,569	$3,117,138	26,113	203
Centre City	1,497	3	0	85	11	7,607	19,253	890,175	$1,780,350	2,096	16
Clairemont Mesa	8,548	15	2	49	33	204,258	516,982	3,223,054	$6,446,108	56,280	438
College Area	1,967	27	4	51	18	83,530	211,417	1,050,045	$2,100,090	23,015	179
Del Mar Mesa	2,062	32	25	10	31	101,510	256,925	483,763	$967,526	27,969	218
East Elliott	2,902	7	21	17	55	30,253	76,570	1,023,572	$2,047,144	8,336	65
Encanto	3,812	15	1	51	30	86,445	218,795	1,550,074	$3,100,148	23,818	185
Fairbanks Country Club	792	17	7	11	52	20,875	52,835	361,498	$722,996	5,752	45
Greater Golden Hill	738	13	0	57	29	14,809	37,482	323,871	$647,742	4,080	32
Greater North Park	2,256	13	1	63	23	44,884	113,602	1,028,531	$2,057,062	12,367	96
Kearny Mesa	4,419	8	2	63	24	52,676	133,325	1,864,732	$3,729,464	14,514	113
La Jolla	5,715	12	4	53	30	110,893	280,672	2,109,335	$4,218,670	30,555	238
Linda Vista	2,717	14	4	48	34	57,862	146,450	934,060	$1,868,120	15,943	124
Mid-City: City Heights	2,931	14	1	65	19	65,229	165,095	1,470,663	$2,941,326	17,973	140
Mid-City: Eastern Area	3,111	16	2	57	24	77,983	197,378	1,323,166	$2,646,332	21,487	167
Mid-City: Kensington -Talmadge	1,161	27	4	50	18	49,809	126,068	626,553	$1,247,106	13,724	107
Mid-City: Normal Heights	837	19	4	60	17	24,531	62,088	446,691	$893,382	6,759	53
Midway-Pacific Hwy.	904	3	0	84	12	4,723	11,953	536,178	$1,072,356	1,301	10
Mira Mesa	10,839	16	4	48	28	264,253	668,831	3,995,062	$7,990,124	72,810	567
Miramar Ranch North	1,894	16	8	44	31	47,225	119,528	1,204,020	$2,408,040	13,012	101
Mission Beach	219	0	0	98	1	0	0	0	0	0	0
Mission Valley	3,212	11	1	58	21	56,402	142,754	1,569,045	$3,138,090	15,541	121
Navajo	9,078	19	11	42	25	272,099	688,690	5,750,999	$11,501,998	74,972	584
Ocean Beach	742	3	0	68	24	3,894	9,856	335,870	$671,740	1,073	8
Old San Diego	265	14	0	57	29	5,778	14,625	116,006	$232,012	1,592	12
Otay Mesa	9,308	5	5	44	21	68,580	173,577	3,660,543	$7,321,086	18,896	147
Otay Mesa-Nestor	5,314	8	2	42	29	70,214	177,712	2,258,032	$4,516,064	19,346	151
Pacific Beach	2,640	3	2	71	23	12,516	31,678	1,193,997	$2,387,994	3,449	27
Pacific Highlands Ranch	2,650	13	6	14	36	51,788	131,078	727,920	$1,455,840	14,269	111
Peninsula	5,269	13	3	47	35	105,365	266,683	1,811,891	$3,623,782	29,032	226
Rancho Bernardo	6,578	19	6	45	29	191,699	485,196	4,513,168	$9,026,336	52,820	411
Rancho Encantada	2,685	11	63	11	16	44,466	112,545	890,975	$1,781,950	12,252	95
Rancho Penasquitos	6,474	20	17	29	33	201,576	510,193	3,306,599	$6,613,198	55,541	432
Sabre Springs	1,577	20	8	34	37	48,889	123,739	931,212	$1,862,424	13,471	105
San Pasqual	10,585	14	20	16	43	229,460	580,769	4,497,914	$8,995,828	63,224	492
San Ysidro	1,875	8	0	60	25	23,726	60,052	855,044	$1,710,088	6,537	51
Scripps Miramar Ranch	4,191	21	14	34	27	136,602	345,744	2,589,519	$5,179,038	37,638	293
Serra Mesa	2,207	13	3	49	33	43,661	110,508	758,274	$1,516,548	12,030	94
Skyline-Paradise Hills	4,580	15	1	54	28	104,623	264,804	1,815,282	$3,630,564	28,827	224
Sorrento Hills	827	3	4	72	20	4,226	10,697	0	$0	1,164	9
Southeastern	2,928	9	0	65	24	41,115	104,063	1,333,535	$2,667,070	11,329	88
Tierrasanta	7,246	15	12	28	43	173,263	438,533	1,696,893	$3,393,786	47,740	372
Tijuana River Valley	3,573	15	9	18	31	81,044	205,125	1,157,096	$2,314,192	22,330	174
Torrey Highlands	1,544	7	4	36	42	16,466	41,675	871,021	$1,742,042	4,537	35
Torrey Pines	2,719	7	10	46	19	29,673	75,103	1,147,472	$2,294,944	8,176	64
University	8,674	13	9	49	28	174,873	442,609	2,980,481	$5,960,962	48,183	375
Uptown	2,681	18	1	52	28	74,495	188,548	1,084,924	$2,169,848	20,526	160
Via de la Valle	133	6	20	26	48	1,274	3,224	24,348	$48,696	351	3
Total	**181,824**	**13%**	**10%**	**39%**	**30%**	**3.8 million**	**9.8 million**	**78 million**	**$156 million**	**624,846**	**4,864**

**Note: The entire study area of this project includes other planning areas in addition to the city of San Diego's community planning areas. The city's council districts include additional military, park, and preserve land not included in the community planning areas. Water, wetlands, agriculture/fallow land, and sand acreages are not included in this table.*

***Landcover may equal more than 100% due to rounding.*

This view shows a true color, high-resolution, multispectral satellite scene of San Diego and its surrounding communities collected in 2002.

This image has been classified into different landcovers. The predominant landcovers are tree cover (dark green), grass (light green), shrub (olive), and impervious surface (gray). With this digital green data layer and CITYgreen software, communities in San Diego now have the tools they need to put tree canopy into the decision making process. The data produced for this study are flexible enough to provide critical decision support for any location.

Green Data Layer Applied to Local Issues

Once imagery is classified into different land cover categories, a green data layer—a highly accurate representation of a city's green infrastructure—is ready for local use. This data layer can be used to improve planning, design, and development decisions. Using a green data layer, cities can measure their tree cover and set attainable canopy goals. By setting stratified tree cover goals for different development zones such as residential, commercial, industrial, and open space, local leaders can begin to bring the green infrastructure back into balance with the gray. Here are a few examples of how the green data layer can be integrated into the city of San Diego's environmental planning and policies.

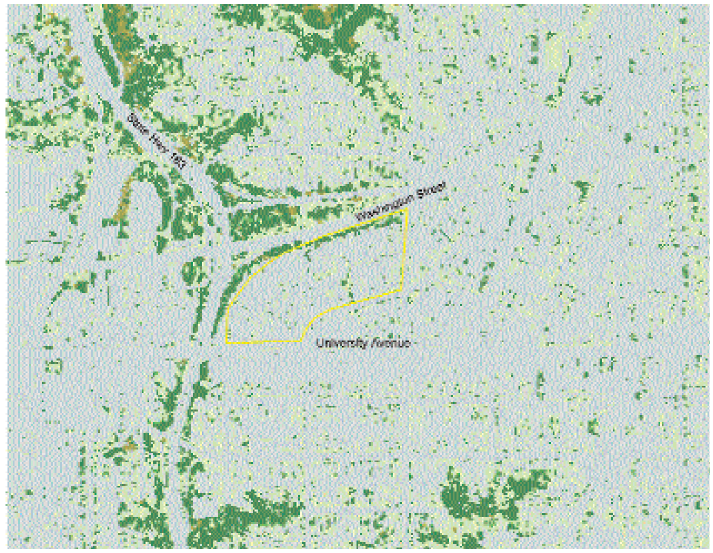
City of Villages Strategy/Uptown District

The City of Villages strategy is the adopted method for guiding growth and development over the next two decades. This design strategy addresses growth and will improve existing communities by combining housing, commercial, employment centers, schools, and civic uses with transit service in areas where a high level of activity already exists. For example, analysis of the Uptown District, which is a site that exemplifies the land use recommendations in the "City of Villages" strategy, could show if these land use recommendations are beneficial in terms of tree canopy improvements. Prior to redevelopment, the Uptown District was almost entirely impervious surfaces. Using the green data layer and CITYgreen software, the environmental benefits of the City of Villages strategy demonstrates the positive impacts this strategy has on air quality and stormwater runoff. As of 2002, the district has an 80% impervious surface, 6% tree canopy, 14% grassland and no shrub cover. Currently, this district provides 8,300 cubic feet in stormwater services valued at $16,000, removes 138 lbs. of air pollutants valued at $350 annually, and stores 38 tons and sequesters 600 lbs./year of carbon. This is a beginning of an upward trend; environmental benefits will increase as the recently-planted trees mature.

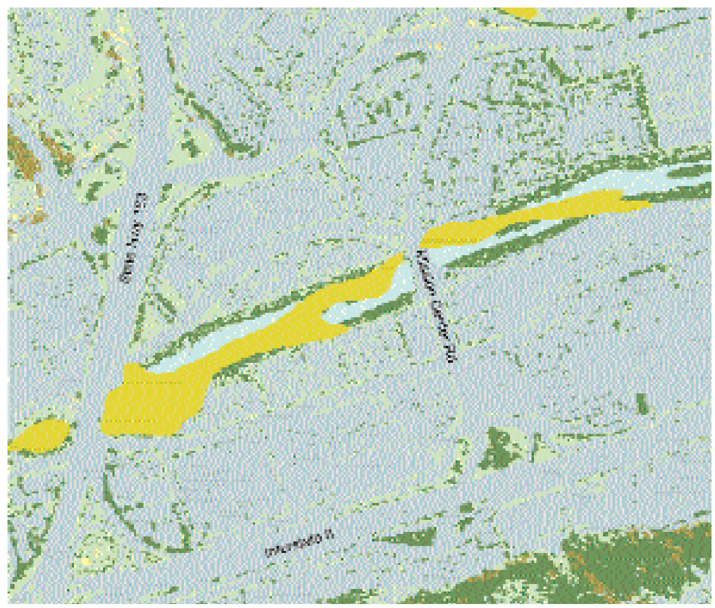
San Diego River Area

In the 504-acre area including a portion of the San Diego River shown here, the green data layer identifies the vegetative resource. This area provides $527,000 in stormwater management services, removes 10,413 lbs. of air pollutants valued at $26,355 and, stores 2,869 tons and sequesters 22 tons/year of carbon.

Uptown District



San Diego River Area



San Diego River

Left: *A Management Plan for the San Diego River's entire watershed is currently under development. The river is also the focus of a project to enhance the river and develop a river park that stretches from its headwaters to the Pacific Ocean. Trees are an important element of watershed management, river enhancement and park development. The green data layer and CITYgreen can be used to model proposed changes. For example, a 100-foot existing tree buffer along a 2-1/2 mile stretch of San Diego River in Mission Valley (District 6) provides a 32% canopy cover and 29,000 cubic feet of stormwater detention services valued of $58,108 in this scenario. If the canopy were increased to 50%, stormwater runoff would be reduced by 36% at an additional value of $33,000.*

Rose Creek

Left: *Many urban pollutants drain from large watersheds into San Diego's creeks, bays and the Pacific Ocean. Trees planted along riparian areas and throughout the watershed can help slow stormwater and filter pollutants before entering these waterways. Using CITYgreen and the data provided, air and stormwater benefits can be calculated.*

Environmental Benefits of Urban Forests

Trees as Indicators of a Community's Ecological Health
Urban ecology is more complex than tree cover. Trees, which make up the majority of the green infrastructure, are good indicators of the health of an urban ecosystem. When trees are large and healthy, the ecological systems that support them (soil, air and water) are also healthy. In turn, healthy trees provide valuable environmental benefits. There is a large difference in the ecological health and characteristics of areas within this region that have more tree cover than others. Comparing the amount of tree cover to impervious surface cover is another important indicator of the health of a community. The greater the canopy coverage and the less the impervious surface, the more environmental benefits.

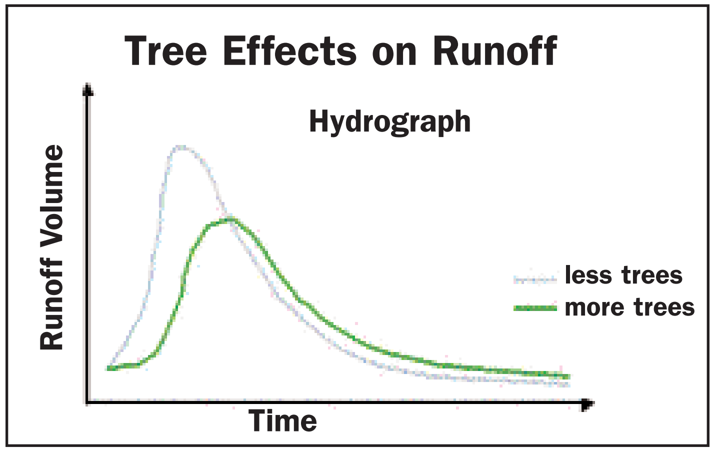
Trees provide communities with many important benefits, not all of which can be measured in terms of dollar value. This report focuses on just two of the benefits that can be calculated for their "bottom line" contributions: stormwater management and air quality improvement.

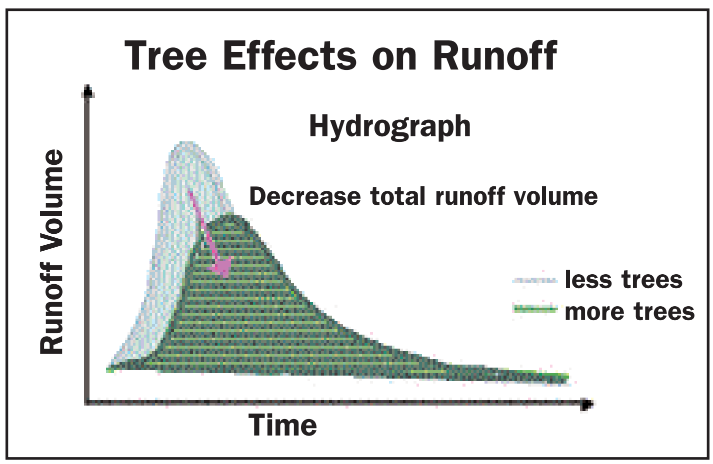
Stormwater Runoff
Trees and soil function together to reduce stormwater runoff. Trees reduce stormwater flow by intercepting rainwater on leaves, branches, and trunks. Some of the intercepted water evaporates back into the atmosphere, and some soaks into the ground reducing the total amount of runoff that must be managed in urban areas. Trees also slow storm flow, reducing the volume of water that a containment facility must store. The TR-55 model, developed by the Natural Resources Conservation Service, measures stormwater movement in various storm events and provides the basis for the calculations used in this study.

Local governments are increasingly looking toward non-built stormwater management strategies, including trees, to reduce the cost of constructing stormwater control infrastructure. The value of trees for stormwater management in this study is based on avoided cost for storage of stormwater in retention ponds. Local construction costs for building containment facilities are multiplied by the total volume of avoided storage to determine dollars saved by trees.

In the city of San Diego, the existing tree canopy reduces the need for retention structures by 82 million cubic feet. Using a $2.00/cubic foot construction cost, trees potentially saved the region $164 million per 20-year construction cycle.

How Trees Slow Stormwater Runoff





Environmental Benefits Summary from High-Resolution Satellite Data*

Area	Acres	Air Pollution Removed Annually (pounds)	Air Pollution Value (Annually)	Retention Volume Required to Mitigate Loss of Trees cu. ft. (2-yr, 24-hr storm)	Stormwater Control Value (One-time Value)	Carbon stored (Total Tons)	Carbon Sequestered (Tons Annually)
City of San Diego	217,572	4.3 million	$10.8 million	82 million	$164 million	1.2 million	9,144
Study Area	319,493	6.3 million	$16.1 million	109 million	$219 million	1.7 million	13,609

Note: Acreage differs from Landsat due to rounding.

**One-page analysis reports for the city of San Diego's individual council districts and community planning areas along with 11 other communities are included as an addendum to this report (see sample on page 16).*

Air Quality

Trees provide air quality benefits by removing pollutants such as NO_2, CO, SO_2, O_3, and PM10. To calculate the dollar value for these pollutants, economists multiply the number of tons of pollutants by an "externality cost" or costs to society that are not reflected in marketplace activity. The value represents costs that society would have paid in areas such as health care, if trees did not remove these pollutants. Air pollution benefits are calculated annually. In the city of San Diego, the trees potentially removed 4.3 million pounds of pollutants annually, valued at $10.8 million.

Stored and Sequestered Carbon

The carbon-related function of trees is measured in two ways: storage, or the total amount currently stored in tree biomass, and sequestration, the rate of absorption per year. Tree age greatly affects the ability to store and sequester carbon. Older trees store more total carbon in their wood and younger trees sequester more carbon annually. Trees' ability to absorb atmospheric carbon reduces greenhouse gases, thought to contribute to global warming. The city of San Diego's trees sequester about 9,000 tons per year and store a total of 1.2 million tons.

Courtesy of the City of San Diego.

AMERICAN FORESTS americanforests.org

Analysis Report

CITYgreen calculating the value of nature

Site Statistics

Analysis Area:	Mid-City: Kensington-Talmadge	Landcover distribution:			Acres
Scenario:	Current Conditions	50%	Impervious		580.28
Area:		18%	Grass		208.47
1.81	sq. miles	4%	Shrub		48.45
1,161.10	acres	27%	Tree Canopy		318.94
469.90	hectares				

Ecological Benefits

	lbs Removed	Dollar Value
Ozone:	21,631	$66,397
oxide:	2,277	$1,713
oxide:	7,970	$24,463
atter:	15,937	$32,628
	1,993	$868
	49,809	**$126,068**

Carbon Storage and Sequestration

Age Distribution of Trees:	Average or Unknown	
Carbon Storage:	13,724	tons
Carbon Sequestration:	2,164.68	tons/year

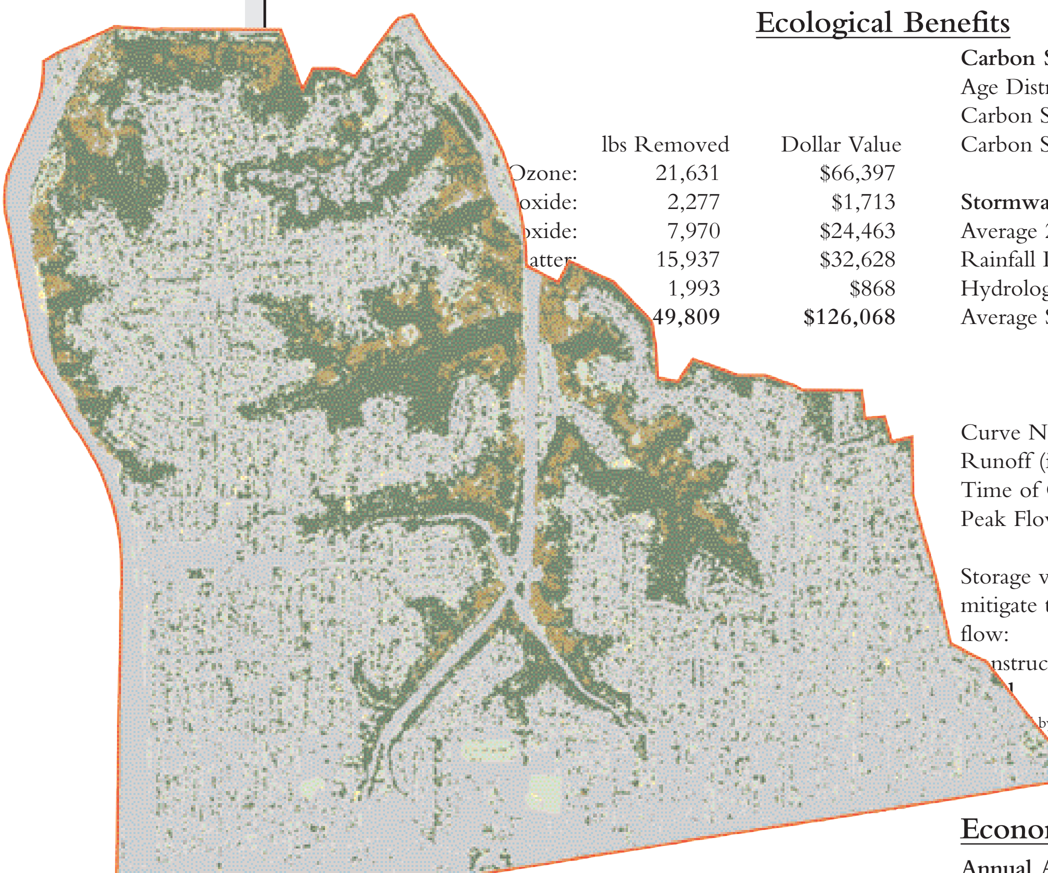
Stormwater Control

Average 2-yr. 24-hour Rainfall:	1.75 in.
Rainfall Distribution Type:	I
Hydrologic Soil Group	C
Average Slope:	9%

	Conditions: Current	w/o trees*
Curve Number:	86	91
Runoff (in.)	0.66	0.95
Time of Concentration (hrs.)	12.24	10.07
Peak Flow (cu ft/s):	46.40	79.95

Storage volume needed to mitigate the change in peak flow:	623,553.00	cu. ft.
nstruction cost:	$2.00	per cu. ft.
l	**$1,247,106.00**	

by default landcover: Urban



Economic Benefit Summary

Annual Air Pollution Removal Savings:	**$126,068**
Annual Stormwater Savings*:	**$108,728**
Total Annual Savings:	**$234,796**

*Annual Stormwater savings is based on financing over 20 years at 6%.

An analysis of the Mid-City: Kensington-Talmadge community planning area demonstrates how this green data layer is used with CITYgreen to produce a one page Analysis Report of the area's environmental benefits. The green and gray represent the area's tree canopy and impervious surface respectively.

Recommendations

The land cover trends from the Landsat satellite analysis reveal that the entire San Diego study area has lost significant tree cover over the last two decades (a 29% decline between 1985-2002) while the urban areas have increased 41%. The changes in the landcover measured by the Landsat imagery are significant. The combination of loss of natural tree, shrub, and grass areas and the increase in the impervious surfaces suggest increased stormwater flow rates while reducing green infrastructure. This trend needs to be reversed.

The recommendations below suggest ways that the green data layer can be incorporated into the San Diego study area's existing policies and programs.

1. Set Tree Canopy Goals.

- The city of San Diego and surrounding communities should set tree canopy goals. The city of San Diego should translate its goals into specific tree cover targets for each of the 52 community planning areas that make up the city.

- Develop a replacement value for existing trees based on biomass.

- Below AMERICAN FORESTS has provided generalized target goals for San Diego, with consideration to its existing tree cover, climate, rainfall, and geography, but realizes that every community is different and needs to have its own goals. The greater the increase in tree canopy the greater the increase in benefits. For example, if city of San Diego were to increase its overall tree cover from 13% (identified by high resolution imagery) to 25%, the increased tree cover would provide 107 million cubic feet in stormwater services, valued at $214 million, increase its air pollution mitigation to 8.5 million lbs. valued at $22 million annually, and store 2.3 million tons and sequester 18,000 tons/year of carbon.

  25% tree canopy overall
  30% tree canopy in suburban residential
  20% tree canopy in urban residential
  10% tree canopy in central business districts

- The tree cover in the College Area and Mid-City: Kensington-Talmadge Area is 27%. While not at their tree potential, they still offer a green infrastructure model that could help the city address many environmental issues and significantly reduce air and water management costs.

2. Increase the tree cover and other vegetation throughout the city so that the natural landscape is sufficient in mass to provide significant benefits to the city in terms of air and water management.

3. Integrate the green data layer provided to the city as part of this analysis into municipal and county GIS systems.

- Distribute the green data layer to municipal and county agencies that monitor air and water quality and stormwater management. Examples include the city of San Diego Storm Water Pollution Prevention Program and the County of San Diego Air Pollution Control District.

- Require all new development projects to provide decision makers with calculations on the impact of their development on air and water systems.

4. Develop specific urban forest management strategies to achieve tree cover goals.

- Design suitable spaces to accommodate trees and select the right tree for the right space so that they grow to their full potential and avoid negative impacts with urban infrastructure.

- Plant and promote the planting of water-conserving trees.

- Plant and promote the planting of the right trees in the right places to improve stormwater management goals.

- Devise methods of keeping leaves out of stormdrains (rather than not plant trees).

- Plant trees to shade roads, parking lots and other impervious surfaces to cool the urban heat island.

- Direct the use of best management practices for tree planting and maintenance in the design of new communities, rights-of-way, etc.

5. Use the green data layer and CITYgreen software to test new strategies for increasing tree cover.

- Document the environmental benefits of a mature tree canopy vs. a new canopy to weigh the cost benefits of conserving trees on site instead of removing and replanting trees.
- Use the modeling capabilities of CITYgreen to determine the impacts of adding or removing tree canopy, impervious surfaces and other land covers.

6. Use the findings of this study to address future land-use planning and growth management adopted in the City of Villages strategy

- Encourage the use of mass transit systems instead of larger roads and more parking lots, thus allowing for the conservation of tree cover.
- Add tree cover into stormwater management planning to improve the water recharge zones, critical in capturing water from smaller rainstorms and improving water levels of local waterways.
- Integrate trees into mixed use and areas along mass transit corridors to promote walkable routes.

7. Use the findings of this study to support the Multiple Species Conservation Preserve.

- Share the green data layer with participating jurisdictions, agencies, and other partners in this effort.
- Use the green data layer to design other open spaces, such as urban canyons located outside of protected MSCP, so as to conserve vegetation resources during development.
- Use the green data layer to help create open space linkages between neighborhoods.

Courtesy of the City of San Diego.

8. Use CITYgreen software to promote public understanding of the environmental benefits of green infrastructure.

- Make the green data layer readily available to community groups.
- Empower the public to think of trees as a valuable element of the urban environment. Set up workshops for community groups on how to use CITYgreen software in their communities as a decision support tool for making good decisions on private property as well supporting trees on public property.
- Update the tree cover analysis every five years to track future trends in forest canopy and associated benefits.

About the Urban Ecosystem Analysis

AMERICAN FORESTS' Urban Ecosystem Analysis is based on the assessment of "ecological structures"—unique combinations of land use and land cover patterns. Each combination performs ecological functions differently and is therefore assigned a different value. For example, a site with heavy tree canopy provides more stormwater reduction benefits than one with lighter tree canopy and more impervious surface.

Data Used

For the time sequence analysis (page 6), Landsat Satellite TM (30 meter pixel) images were used as the source of landcover data. AMERICAN FORESTS used a knowledge-based classification technique to divide the landcover into eight categories (water, wetlands, shrubland, grassland, trees, urban, sand, and bare ground).

To create the green data layer, high-resolution (4 meter pixel) multispectral imagery was obtained from an airborne sensor. AMERICAN FORESTS used a knowledge-based classification technique to categorize different land covers (water, wetlands, shrubland, grassland, trees, impervious surface, sand, and bare ground). Classified Landsat imagery was resampled to 4 meters and used to fill in remaining gaps in the multispectral analysis (8.3% of total land area).

Analysis Formulas

An analysis was conducted for city of San Diego and portions of surrounding communities using CITYgreen® version 5.0. The analysis used the raster data land cover classification from the high-resolution imagery for the analysis. The following formulas are incorporated into CITYgreen software.

TR-55 for Stormwater Runoff: The stormwater runoff calculations incorporate formulas from the Urban Hydrology of Small Watersheds model, (TR-55) developed by the US Natural Resources Conservation Service (NRCS), formerly known as the US Soil Conservation Service. Don Woodward, P.E., a hydrologic engineer with NRCS, customized the formulas to determine the benefits of trees and other urban vegetation with respect to stormwater management.

UFORE Model for Air Pollution: CITYgreen uses formulas from a model developed by David Nowak, PhD, of the USDA Forest Service. The model estimates how many pounds of ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide are deposited in tree canopies as well as the amount of carbon sequestered. The urban forest effects (UFORE) model is based on data collected in 50 US cities. Dollar values for air pollutants are based on averaging the externality costs set by the State Public Service Commission in each state. Externality costs are the indirect costs to society, such as rising health care expenditures as a result of air pollutants' detrimental effects on human health.

Data Available

As part of this project, a complete digital green data layer has been created of the city of San Diego and of 11 other communities/cities within the study area—Bostonia, Coronado, Del Mar, El Cajon, Imperial Beach, La Mesa, Lemon Grove, National City, Poway, Santee, and Solana Beach. An environmental benefits analysis report for each of these communities is available from AMERICAN FORESTS. A digital green data layer is available to any of these communities that wish to use it along with CITYgreen software to conduct their own analyses for future planning.

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City of San Diego Community Forest Advisory Board
California Polytechnic State University
Environmental Systems Research Institute Inc (ESRI)
ERDAS Inc. for remote sensing software

For More Information

AMERICAN FORESTS, founded in 1875, is the oldest national nonprofit citizen conservation organization. Its mission is to grow a healthier world. For information on the organization or to view Urban Ecosystem Analysis reports from other cities visit our web site.

AMERICAN FORESTS' CITYgreen® software provides individuals, organizations, and agencies with a powerful tool to calculate the value of natural systems in urban areas. AMERICAN FORESTS offers training workshops and technical support for CITYgreen and is a certified ESRI developer and reseller of ArcView® products. For further information contact:

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