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A Clear Blue Future

How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century

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Table of Contents

Executive Summary

As global warming threatens our water resources, communities are faced with a need to respond quickly and economically to water supply shortfalls. Both the snowpack and surface runoff that form a critical supply of potable water for western states are being affected by higher temperatures. Low impact development, or LID, is a land planning and engineering design approach to stormwater management that enables cities, states, and individuals to increase access to safe and reliable sources of water while reducing the amount of energy consumed and global warming pollution generated by supplying the water. New NRDC and UCSB analysis shows that implementing LID practices at new and redeveloped residential and commercial properties in parts of California can increase water supplies by billions of gallons each year, providing an effective and much-needed way to mitigate global warming's impact on California.

LID Techniques Can Deliver Water and Energy Savings for Californians

The NRDC and UCSB analysis found that implementing LID practices that emphasize rainwater harvesting, which includes infiltration of water into the ground as well as capture in rain barrels or cisterns for later use onsite, at new and redeveloped residential and commercial properties in the urbanized areas of southern California and limited portions of the San Francisco Bay area has the potential to increase local water supplies by up to 405,000 acre-feet (af) of water per year by 2030. This volume represents roughly two-thirds of the volume of water used by the entire City of Los Angeles each year. The water savings translate into electricity savings of up to 1,225,500 megawatt hours (MWh), avoiding the release of as much as 535,500 metric tons of CO_2 per year, as the increase in energy-efficient local water supply from LID results in a decrease in the need to obtain water from imported sources of water such as the California State Water Project (SWP) or the use of processes such as ocean desalination, both of which require tremendous amounts of energy. These benefits would increase in each year thereafter.

One acre-foot of water is the volume of water (325,851 gallons) that will cover an acre of land—or a football field to the 91 yard line—to a depth of one foot. An acre-foot is enough water to supply two families in California for a full year.

And the true value of LID is likely much higher. Our analysis currently assumes a conservative figure for future development rates and does not account for the loss of water that currently occurs as it is conveyed from distant sources. Expanding the use of LID to industrial, government, public use, and transportation development and redevelopment in southern California has the potential to yield an additional 75,000 acre-feet of savings per year by 2030, with corresponding reductions in energy use and CO_2 emissions.

Moreover, even greater overall water and electricity savings—and associated reductions in global warming pollution—would result from full application of LID practices statewide and in other areas of the United States where augmenting local water supplies may reduce the amount of energy required to supply water from more energy-intensive sources.

The 1,225,500 megawatt hours of electricity savings that can be achieved each year through use of LID practices represents enough energy to power more than 102,000 single family homes for one full year.[1] Emissions reductions of 535,500 metric tons of CO_2 each year are the equivalent of taking more than 97,000 cars off the road.[2] The analysis we present in this paper shows that LID can play a significant role in terms of addressing issues of water supply and climate change throughout California and the southwest United States.

Vegetated swale in a parking lot CREDIT: Haan-Fawn Chau

Green roof in Vista Hermosa Park, Santa Monica Mountains Conservancy, Los Angeles / CREDIT: Ken Weston and Reza Iranpour/ City of Los Angeles

LID Technologies Provide Multiple Benefits

LID was developed to ameliorate—and where possible, eliminate—the pollution and erosion problems generated by runoff from urban and suburban development at the source, where rain falls on paved surfaces, by maximizing the natural onsite infiltration and treatment abilities of soils and vegetation or by capturing water for later use. It provides important environmental benefits by reducing pollution of downstream rivers, lakes, and coastal waters.

Successful LID practices include:

- maximizing infiltration, which recharges local and regional groundwater systems;
- providing retention areas and slowing runoff, which reduce flooding and erosion;
- minimizing the impervious footprint of a project through reducing paved surfaces;
- directing runoff from impervious areas onto landscaping; and
- capturing runoff in rain barrels or cisterns for beneficial use.

By preventing site runoff altogether in many situations, LID is substantially more effective at protecting water quality than many types of conventional water management practices that rely on structural treatment devices to remove a percentage of pollution after it has already entered stormwater runoff. In addition to serving as a superior method of stormwater pollution control, LID can increase water supply reliability in a region prone to natural disasters, serve to reduce flooding and erosion associated with urban runoff, reduce the "heat island" effect from solar radiation in urban settings, and provide green space and open land, enhancing property values. The use of LID can also reduce the costs of municipal stormwater infrastructure and decrease the frequency and severity of combined sewer overflow events.

LID Is Cost Effective

The U.S. Environmental Protection Agency (EPA) states that "LID practices can reduce project costs and improve environmental performance" of development and that, with few exceptions, LID has been "shown to be both fiscally and environmentally beneficial to communities."[3] As a result, LID practices can provide a targeted, cost-effective means of addressing issues of water pollution, water supply, and climate change all at once.

Current and Emerging Regulatory Policies Support the Implementation of LID

Federal and state regulatory policies already require that developed sites in larger and midsized cities control post-construction stormwater runoff. Requiring implementation of LID technologies can therefore reduce energy use and global warming pollution and serve as a cost-effective means of complying with existing mandates of federal and state laws.

Groundwater's Role in California's Water Supply

By allowing more water to infiltrate the ground and recharge aquifers, LID can reduce demand for energy-intensive imported water or desalinated ocean water. Recharging these aquifers is particularly useful given that most areas of the state already have infrastructure in place to extract and distribute groundwater. California extracts more groundwater—approximately 17 million acre-feet per year—than any other state in the country. As much as 50 percent of the state's population receives some portion of their potable water supply from groundwater, including the vast majority of urbanized southern California areas that also receive a portion of their water from energy-intensive sources in northern California. In fact, nearly 50 percent of the total population of the United States depends on groundwater for some part of their water supply, meaning that LID practices can be used to help recharge local and regional groundwater aquifers across large portions of the country.

The reliance on groundwater is particularly strong in southern California where an average of 1.56 million acre-feet per year—or about 40 percent of the region's total water needs—are met through local groundwater pumping. Rainwater is the primary source that recharges the aquifers, and the Metropolitan Water District of Southern California recently estimated that ground water basins in the southern California region have 3.2 million acre-feet of storage space available for possible recharge. This existing capacity underlines the potential for LID practices that emphasize infiltration to greatly enhance local groundwater supplies. The use of LID represents a practical solution to California's water supply needs.

Capturing Rooftop Runoff

For areas where surface soil conditions, aquifer capacity, or traditional water supply patterns may favor capturing runoff rather than groundwater recharge, practices that promote capture and beneficial use provide a similar opportunity to reduce energy use and greenhouse gas (GHG) emissions. LID practices for capturing rainfall can reduce runoff volumes by as much as 75 percent, saving much of the water to be used onsite.

The Climate Challenge

Global warming is already affecting water resources in California, and temperatures are projected to rise by as much as 8 to 10.5 degrees Fahrenheit in the state toward the end of the century. The Sierra snowpack, which forms California's largest freshwater surface reservoir and serves as a critical source of drinking and agricultural irrigation water, is expected to shrink by between 25 and 40 percent by 2050, and as much as 70 to 90 percent by the end of the century, drastically increasing the strain on a water management system that will be needed to supply an additional 24 million people by midcentury. Reservoirs along the Colorado River, which supply large portions of the southern California population, have slowly emptied to less than half their capacity as drought conditions grip the region. California must look for fresh and innovative ways to address climate change and reduce the emission of greenhouse gases that threaten its water supply.

The safe and sufficient supply of water in California is both a casualty of global warming and a contributor to it. Water must often be conveyed long distances and at great energy cost that results in substantial GHG emissions. In fact, water now constitutes one of the largest uses of energy in California, consuming an astonishing 19 percent of all electricity and 33 percent of non-power-plant natural gas used in the state. A significant portion of the electricity, substantially more than the national average, is used for the conveyance of water. The California State Water Project (SWP), which pumps water a distance of 444 miles from the Sacramento-San Joaquin Delta to southern California, and lifts the water from just above sea level at the Delta nearly 3,000 feet over the Tehachapi Mountains in the process, is the single-largest individual user of electricity in the state. And as California confronts issues related to limited water supplies and a growing economy, 20 ocean desalination plants have been proposed statewide, each of which would supply water at an energy cost comparable to conveying water through the SWP. By contrast, the energy required to supply groundwater can be 5 to 20 times less than that required to supply water through the SWP or ocean desalination, and the energy required for capture and onsite use of stormwater can be 8 to more than 25 times less—if there are any energy requirements at all. LID presents a way to augment local water supply and avoid the energy consumption and GHG emissions associated with transporting water over long distances.

The white "bathtub rings" show the pre-drought water level of Lake Powell in Arizona. In March 2008, the lake's water levels had fallen more than 100 feet below its corresponding levels a decade ago.

PHOTO CREDIT: Mike Reyfman, *Lake Powell.*

The LID Solution

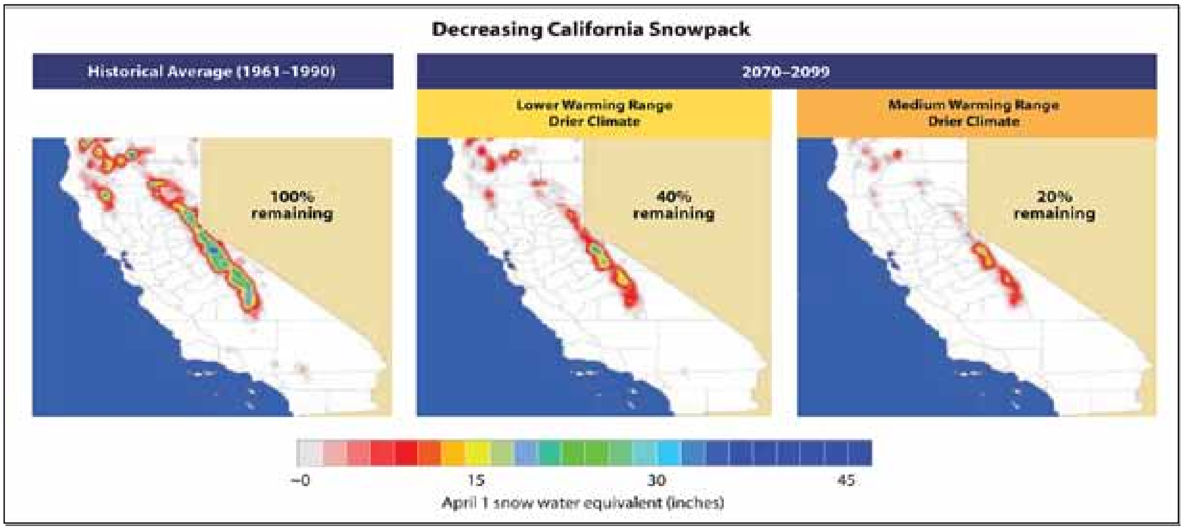
LID provides new ways to adapt to and mitigate the serious challenges to our water supply posed by global warming. Our study indicates that rainwater harvesting through use of LID can be of considerable help to California—and at bargain prices. LID can play a significant role in addressing water supply and global warming challenges throughout California and the southwestern United States.

GLOBAL WARMING

Global warming is already affecting water resources throughout the western United States. The California Department of Water Resources (DWR) states that, although "the exact conditions of future climate change remain uncertain, there is no doubt about the changes that have already happened."[1] According to DWR, "[t]he average early spring snowpack in the Sierra Nevada decreased by about 10 percent during the last century, a loss of 1.5 million acre-feet of snowpack storage."[2] Forming the largest freshwater reservoir in California, the Sierra snowpack is a critical source of water for the entire state. "Snowmelt currently provides an annual average of 15 million acre-feet of water, slowly released between April and July each year. Much of the state's water infrastructure was designed to capture the slow spring runoff and deliver it during the drier summer and fall months."[3] However, changes as a result of global warming threaten the continued viability of this vital water source. Largely because of temperature increase, the Sierra snowpack is projected to shrink by between 25 to 40 percent by 2050, and as much as 70 to 90 percent by the end of the century (see Figure 1).[4,5]

The rise in temperatures in the Sierra Nevada Mountains has two major implications for California's water supply. First, "more precipitation is falling as rain and less as snow."[6] An air temperature increase of 1.8°F (1°C) is predicted to reduce the average annual volume of water produced from snowmelt by approximately 15 percent, while a 7.2°F (4°C) increase would result in about a 60 percent reduction in snowmelt.[7] Second, snowmelt is occurring progressively earlier in the season.[8] In the early spring, man-made reservoirs in California are operated for flood control purposes. Water must be released from the reservoirs, rather than stored, to protect against the possibility of storms or heavy precipitation events late in the wet season. As snowmelt and the resulting runoff shifts to earlier times in the year, it reduces the amount of water

Figure 1: Projected dry-climate reduction in the Sierra Nevada snowpack, from 2070–2099; from the California Climate Change Center, 2006. Projections are based on warming ranges of 3–5.5°F (1.7-3.3°C) (Lower Warming Range) and 5.5–8°F (3-4.4°C) (Medium Warming Range). The High Warming Range estimate, which projects a temperature increase of 8 to 10.5°F (4.4 to 5.8°C), is not shown.



SOURCE: California Climate Change Center.

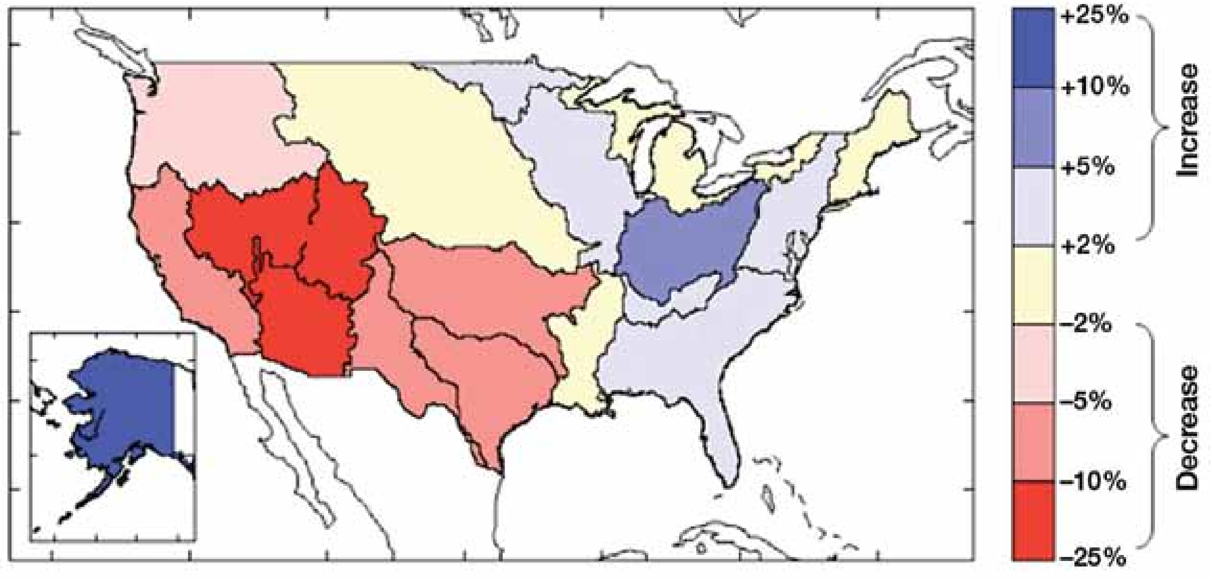
AND WATER

available for storage in California's water supply system. An increase in the average temperature of 7.2°F (4°C) would shift the mean snowmelt runoff from mid-March to mid-February, when reservoirs must still release water. Thus, even if the same volume of snowmelt were to occur in the future, less of the water could be stored and later made available for use during the dry California summer.[9]

Global warming is predicted to have a significant impact on surface streamflow and runoff as a result of the increased temperatures and altered precipitation patterns. The overall surface runoff in California could decrease by up to 10 percent by midcentury, with far greater decreases in runoff in the intermountain Southwest (see Figure 2).[10] With a rise in temperatures of between 5.5 and 8°F (3 to 4.4°C) by the century's end, the medium warming range predicted by the California Climate Change Center, late spring streamflow could drop by as much as 30 percent.[11]

These changes come in addition to projected increases in sea level rise that threaten coastal aquifers with saltwater intrusion, an increase in the number and intensity of extreme storm events that cause erosion and flooding, warmer temperatures that increase evapotranspiration rates and therefore the amount of water needed for irrigation of crops and landscaping, and increased water pollution resulting from rising temperatures and decreased streamflow.[12] There is an urgent need to both manage water and reduce GHG emissions, and LID offers a potential avenue for addressing these concerns. In addition to providing GHG emissions reductions (known as "mitigation" in climate discussions), LID also provides potentially valuable adaptation attributes such as improved water supply reliability and water quality.

Figure 2. Projected changes in runoff for the period of 2041–2060 relative to 1901–1970. Modified from U.S. Climate Change Science Program, 2008.



CHAPTER 1

LOW IMPACT DEVELOPMENT AND THE URBAN ENVIRONMENT

Low Impact Development is a "comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds."[13] Low Impact Development evolved initially as a stormwater management approach aimed at eliminating—or at least ameliorating—the problems generated by runoff from urban and suburban development at the source. By maintaining or restoring natural hydrologic functions, LID can reduce the volume of runoff and associated pollution discharged from a site. LID incorporates a number of practices to accomplish this goal, including: maximizing infiltration, which recharges local and regional groundwater systems; providing retention areas and slowing runoff, which reduce flooding and erosion; minimizing the impervious footprint of a project; directing runoff from impervious areas into landscaping; and capturing water in rain barrels or cisterns for later use.[14] Through the use of harvesting water, by either infiltration or capture, LID can increase the local supply of water and therefore decrease the need to obtain water from imported or other energy-intensive sources. The Los Angeles Economic Development Corporation has recently cited practices that infiltrate or capture stormwater as having the potential to provide "[h]undreds of thousands of acre-feet" of water.[15]

Benefits of LID

LID provides important benefits with respect to water quality, pollution abatement, flooding, and erosion control, and it can be implemented under a wide variety of climactic and geographic settings. LID practices, such as green roofs, can additionally be designed to reduce the "urban heat island effect," thereby reducing the need for air conditioning and other energy-intensive residential and commercial uses of electricity.[16] By increasing green space in development projects, LID can improve overall urban aesthetics and provide natural-looking, pleasing cityscapes. The additional open space created by LID site designs can be especially important for low-income communities otherwise disadvantaged with regard to usable urban outdoor areas.

LID techniques can be put into practice, and the above benefits realized, at a broad range of land use types and scales. The EPA has stated that, "LID can be applied to new development, redevelopment, or as retrofits to existing development. LID has been adapted to a range of land uses from high density ultra-urban settings to low density development."[17] Site specific conditions, which may include low permeability soils or the existence of shallow or contaminated groundwater, may mean that not every individual LID practice can be used at every site. But because of the breadth of available LID techniques and strategies, EPA has stated succinctly, "LID Works Everywhere."[18]

Urbanization, Stormwater, and Pollution

Urbanization and development increase the percentage of impervious cover in the landscape (i.e., roads, rooftops, and parking lots that prevent the infiltration of water into soil). Greater impervious cover, in turn, increases the volume and velocity of runoff that results from precipitation.[19] Overall, "most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development."[20] For example, a one-acre parking lot produces 16 times more runoff than a one-acre meadow.[21] This can lead to increasingly severe flooding and erosion and can greatly amplify levels of pollution in surface waterbodies.[22] When the increased volume of runoff flows over paved surfaces, it picks up proportionally higher levels of automotive fluids and debris, pesticides, pet wastes, trash, and other contaminants and carries them to receiving waters.[23]

As the population has grown across the western United States, an ever-increasing percentage of the landscape has been paved and covered with impervious surfaces, drastically altering the natural hydrologic regime of entire watersheds. Land use maps indicating changing activities and land surface cover in the Chino Basin in San Bernardino County, California exemplify this phenomenon, highlighting the type of rapid and intense urban development that has occurred over the last 50 years (see Figure 3). The depicted large-scale shift from agrarian or open land to urban development is characteristic of many areas of the state, which has seen its population grow from 10.5 million in 1950, to more than 36.7 million in 2008, with a further 24 million expected to settle in the state by midcentury.[24,25,26] With the increased impervious surface comes drastically increased runoff and increased stormwater-related pollution.

As a result, the EPA views urban runoff as one of the greatest threats to water quality in the country and considers it "one of the most significant reasons that water quality standards are not being met nationwide."[27] The EPA found that "54 percent of California's impaired waterways are polluted by runoff."[28] California experienced 4,133 beach closing and advisory days in 2008, and "polluted urban stormwater runoff," i.e., runoff from roads, roofs, lawns, construction sites, and other impervious surfaces, "continues to be the largest source of pollution in Santa Monica Bay and across California."[29]

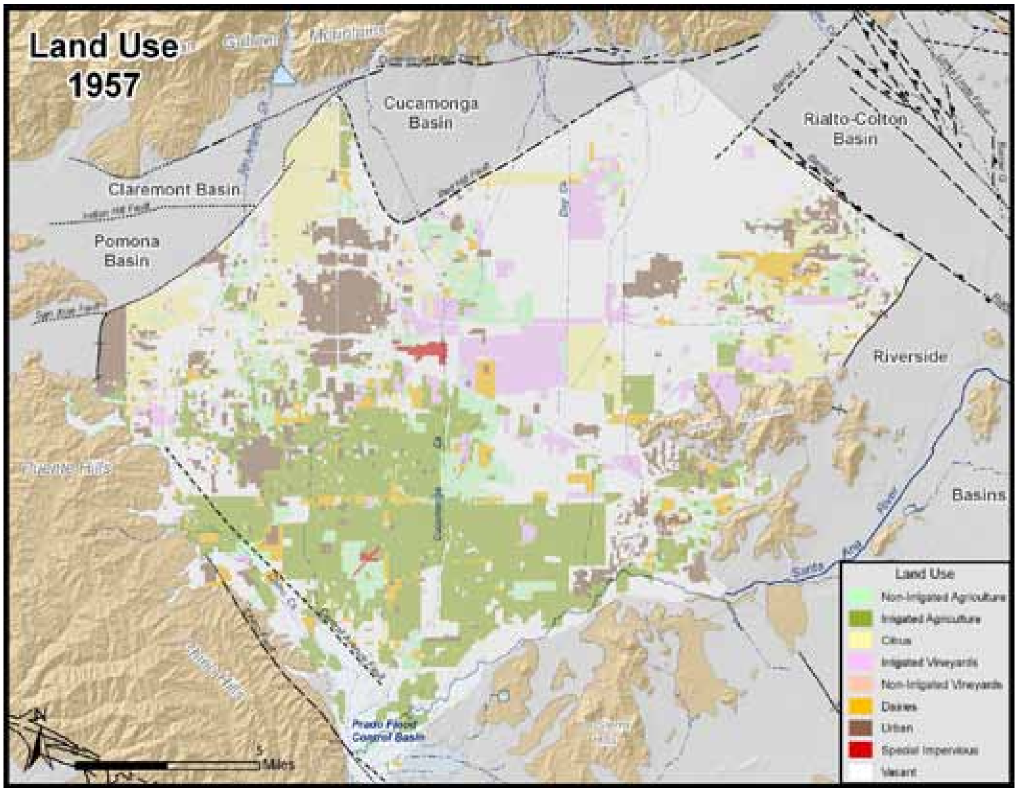


Figure 3a.
Land cover and land use in the Chino Basin, 1957

CREDIT: WILDERMUTH ENVIRONMENTAL, 2009

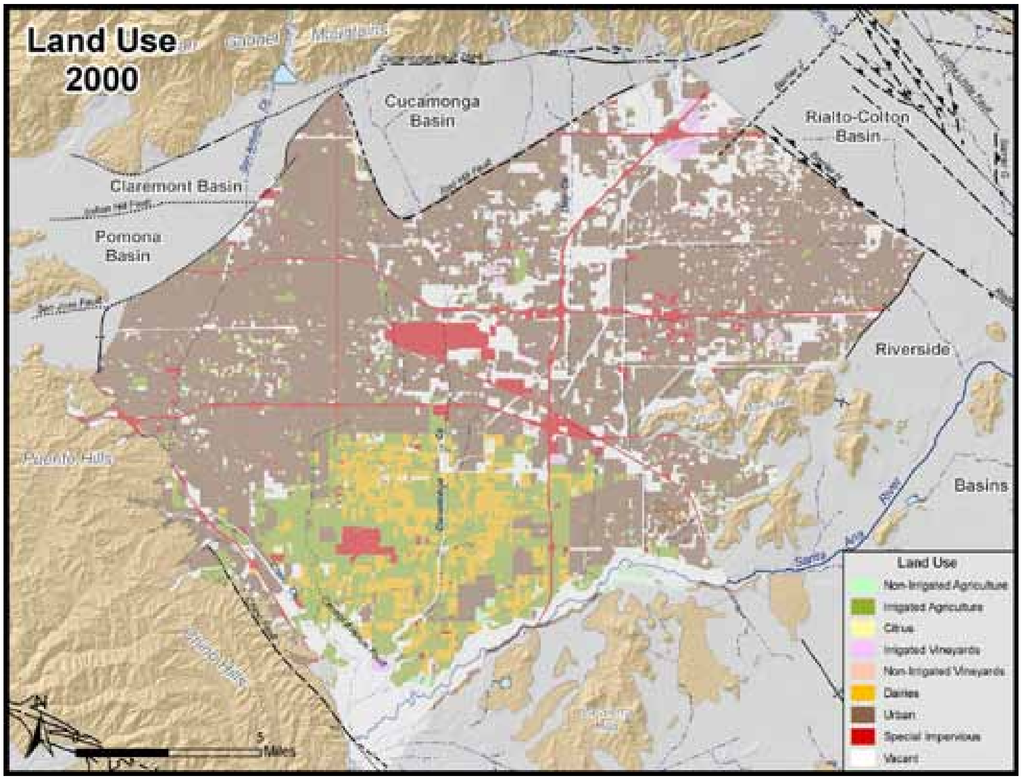


Figure 3b.
Land cover and land use in the Chino Basin, 2000

CREDIT: WILDERMUTH ENVIRONMENTAL, 2009

Stormwater Regulation and Conventional Management Approaches

In order to prevent the pollution and other harms that result from urban runoff, the Federal Clean Water Act requires municipalities, counties, and other dischargers to impose "controls to reduce the discharge of pollutants to the maximum extent practicable."[30] Dischargers must use "management practices, control techniques and system, design, and engineering methods, and such other provisions which are appropriate."[31] To meet these conditions, dischargers apply for permits under the National Pollutant Discharge Elimination System (NPDES) program. Permittees in California have been increasingly required to treat a certain percentage of runoff that sites generate in order to prevent further pollution to the state's waters.[32] For example, in 2001, the California State Water Resources Control Board adopted Order WQ 2000-11, which "created objective and measurable criteria for the amount of runoff that must be treated or infiltrated" and established a requirement that treatment or infiltration occur for "85 percent of the runoff from specified categories of development."[33]

One method of complying with such permit conditions has been to use conventional stormwater management practices to address water quality concerns (as opposed to addressing or limiting the volume of runoff generated at a site directly). With conventional practices, "structural" or engineered solutions are employed to transport runoff away from developed sites as quickly as possible—through curbs, gutters, buried drainage pipes, and centralized combined sewer systems—to treatment facilities or directly to receiving waters.[34] Because treatment occurs in this system, if at all, only after pollutants have already entered stormwater, conventional practices are often less effective than LID at removing pollution in urban runoff and mitigating its impacts on surface waterbodies.[35]

In combined sewer systems, stormwater runoff is collected and conveyed in the same pipe as domestic sewage and industrial wastewater. Under normal conditions, the wastewater is transported to a sewage treatment plant for treatment. However, during periods of heavy rainfall or snowmelt, "the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant."[36] For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other waterbodies, resulting in "stormwater, . . . untreated human and industrial waste, toxic materials, and debris" pouring directly into receiving waters.[37] Consequently, the EPA considers combined sewer overflows to be "a major water pollution concern for the approximately 772 cities in the U.S. that have combined sewer systems."[38] In municipalities that maintain separate sewer systems, which collect and convey stormwater independently of domestic sewage, "polluted stormwater runoff is commonly transported through [the storm sewer], from which it is often discharged untreated into local waterbodies."[39] Use of these conventional controls has been the dominant paradigm for addressing the challenges posed by stormwater across the United States for decades, with unfortunate consequences to the health of our nation's surface waterbodies.


Drainage swale as part of Seattle's SEA (Street Edge Alternatives) Project / CREDIT: EPA/ Abby Hall

Stormwater Management through LID

The California Ocean Protection Council recently found that "LID is a practicable and superior approach" to stormwater management and that LID practices can be used "to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses, coastal resources and communities" at a variety of development and redevelopment projects.[40] LID uses improved design approaches such as strategically placed beds of native plants, rain barrels, green roofs, permeable or porous surfaces for parking lots and roads, and other features to reduce runoff by helping rainfall soak into the ground or to otherwise retain rainfall onsite, rather than allowing runoff to pollute the nearest waterbody. This aspect of LID mimics nature's own infiltration and filtering systems;[41] runoff accumulates less pollution because it flows over less impervious surface. Bioswales, basins, trenches, and other infiltration devices use absorption, settling, and the soil's natural capacity to filter pollutants to achieve 70 to 98 percent contaminant removal.[42] The result is less water pollution from stormwater runoff, reduced flooding, replenished water supplies, and more natural-looking, aesthetically pleasing cityscapes. One recent study concluded that through implementing "Green Solution" projects that "employ soil, plants, and natural processes to capture, filter and clean polluted urban and stormwater runoff" solely on existing public lands within Los Angeles County, nearly 40 percent of the county's polluted runoff clean-up needs could be met.[43] Furthermore, LID strategies that preserve existing vegetation and include vegetated and grassy swales and tree-box filters can help sequester GHG emissions and reduce the "heat island" effect in urban areas.

Under the Clean Water Act, dischargers are required to control post-construction stormwater runoff. In some jurisdictions, use of LID has already become the required paradigm for addressing this runoff.[44] Moving to require the implementation of LID practices simply represents a commonsense means of requiring compliance with the law.

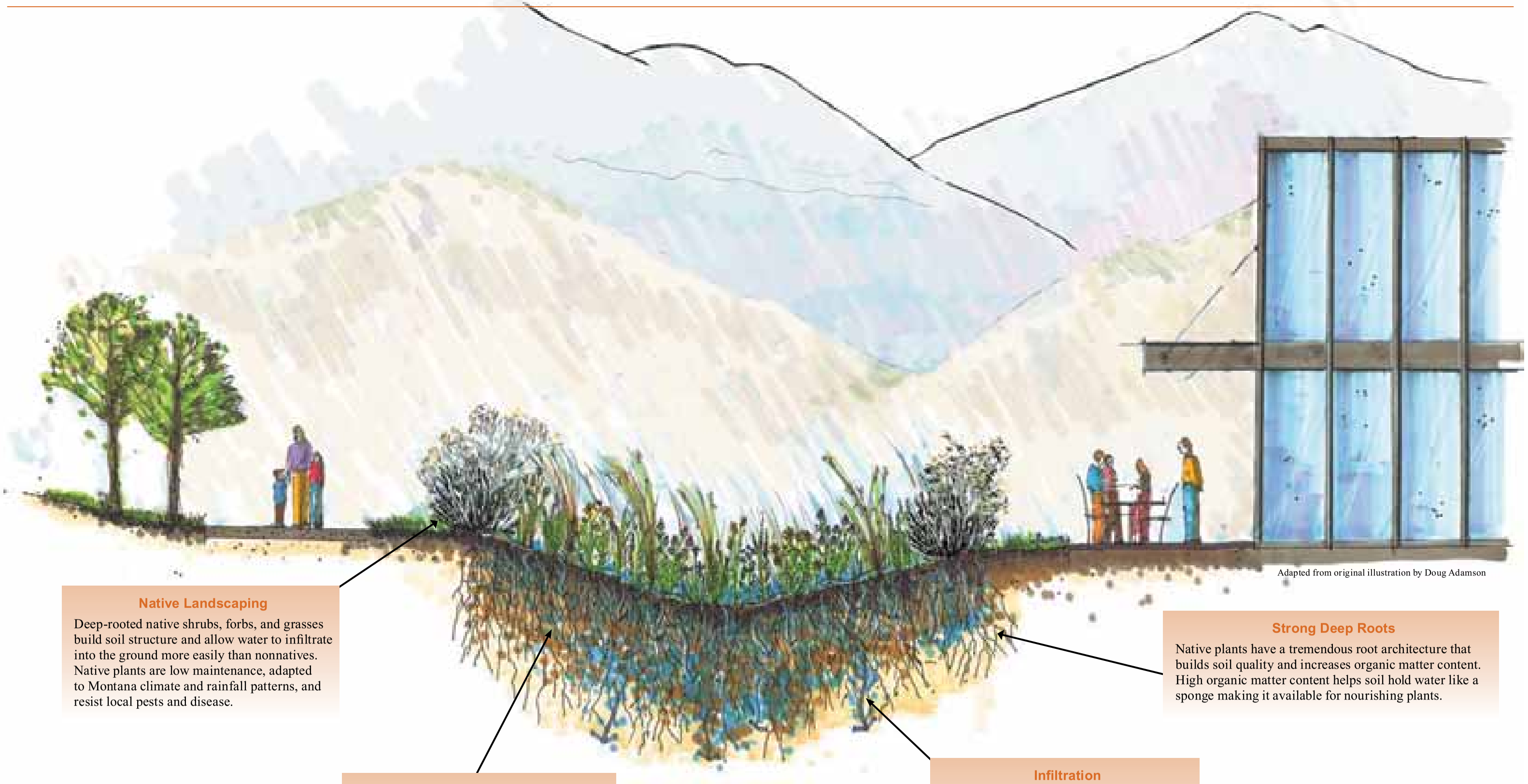
Cost Effectiveness of LID

In addition to the environmental benefits, implementation of LID practices instead of conventional stormwater controls often results in substantial financial savings and provides a valuable water supply at low cost. The EPA has stated that "[i]n the vast majority of cases…implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality."[45] Further, "LID…provides ecosystem services and associated economic benefits that conventional stormwater controls do not."[46] Our findings suggest that increased water supply, energy savings, and GHG emissions reductions should be added to the list of benefits.

Because traditional stormwater management approaches involve the construction of complex systems of infrastructure, they can entail substantial costs. Since LID attempts to mimic the predevelopment hydrology of a site, emphasizing storage and use, infiltration, and use of a site's existing drainage conditions, "[c]ost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized."[47] Although costs of LID implementation vary depending on site and/or project conditions and the specific practices or techniques implemented, with only "a few exceptions," the EPA found that "total capital cost savings ranged from 15 to 80 percent when LID methods were used" instead of conventional stormwater management techniques.[48,49] The City of Seattle found similar savings for street design or improvement projects, as projects that employ natural drainage techniques "cost about 10 to 20 percent less than traditional street redevelopment with curb, gutter, catch basins, asphalt, and sidewalks."[50] Further, because LID practices represent a new technology with initial costs for learning, design, and installation, costs are declining with time.[51] The U.S. Department of Defense notes that, "As with any new approach, the cost of implementing LID will decrease as institutional experience increases and the benefits of using LID are realized in practice."[52]

The savings identified in studies documented by federal and other agencies are all the more noteworthy considering that they count only the costs of installation for LID and conventional controls. The savings identified do not reflect the additional economic benefits that LID provides. This is particularly relevant for projects that capture rainwater; the EPA study stated that for one of the "few exceptions" in the report, the cost of a rooftop runoff capture system installed at a site "was assumed to be offset somewhat by savings on stormwater utility bills" that were not calculated into the cost of the project.[53] Further savings would be available in the form of reduced water bills resulting from the increased availability of onsite supply. In addition to offsetting project costs, LID can result in economically beneficial externalities including reduced costs of municipal infrastructure, greater control of combined sewer overflow (CSO) events, and increased value of real estate.[54,55,56]

Figure 4. Example of a LID practice promoting infiltration (USDA/Iowa NRCS, 2008).[57]



Bioswale in a Corporate Setting

Native Landscaping
Deep-rooted native shrubs, forbs, and grasses build soil structure and allow water to infiltrate into the ground more easily than nonnatives. Native plants are low maintenance, adapted to Montana climate and rainfall patterns, and resist local pests and disease.

Soil Amending
Along with native plantings, soils amended with compost and sand may be needed to facilitate infiltration. A rock trench can be installed down the center of the swale.

Infiltration
Water infiltrated through bioswales helps recharge groundwater, which supplies rivers and streams with a slow, purified seep rather than surges of polluted surface runoff from roofs and other impervious areas.

Strong Deep Roots
Native plants have a tremendous root architecture that builds soil quality and increases organic matter content. High organic matter content helps soil hold water like a sponge making it available for nourishing plants.

Adapted from original illustration by Doug Adamson

Helping People Help the Land NRCS

Examples of LID practices that promote infiltration or capture.

PHOTO CREDIT: Haan-Fawn Chau

Vegetated swales: Vegetated swales are broad, shallow channels with dense stands of vegetation, such as trees, shrubs, or grasses, covering the side slopes and bottom. Swales are designed to trap or filter particulate pollutants, promote infiltration, and reduce the flow velocity and erosive impacts of storm water runoff.[58]

PHOTO CREDIT: Photo courtesy of USDA NRCS

Rain gardens: Rain gardens are small gardens generally planted with native vegetation and designed to withstand extremes of moisture and high concentrations of nutrients such as nitrogen and phosphorous commonly found in stormwater runoff. Rain gardens collect stormwater runoff both to slow the flow of water and give the water more time to infiltrate.[59]

PHOTO CREDIT: EPA/Abby Hall

Porous pavement and permeable pavers : Porous and permeable pavement surfaces absorb water and allow stormwater runoff to infiltrate into the soil beneath the paved surface. Porous pavements may include porous asphalts and porous concretes, which contain little fine grained material, leaving void spaces that allow for rapid percolation of runoff.[60] Permeable pavers create networks of interlocking blocks that allow water to percolate through gaps between the paving blocks.[61]

PHOTO CREDIT: HEPA/Abby Hall

Rainbarrels and cisterns: Rainbarrels and cisterns are used to collect and store rainwater from rooftops or other paved surfaces that would otherwise be diverted to storm sewer systems and lost. The water can then be used for nonpotable purposes such as landscape irrigation or flushing toilets. Rainbarrels typically collect water from gutters and downspouts, and are small, generally inexpensive solutions for smaller residential buildings. Cisterns can vary in size from small household units to large, several thousand gallon tanks, and can be sited above ground or underground.

CHAPTER 2

CALIFORNIA'S WATER SUPPLY, WATER HARVESTING, AND LID

LID practices that emphasize harvesting rainwater, or redirecting and collecting runoff for beneficial use, include two general categories of techniques: use of infiltration to recharge groundwater supplies, or capture for onsite use. Groundwater forms when precipitation falling on land infiltrates the soil and percolates to depth, creating aquifers in water-bearing rock layers. In the natural hydrologic regime, up to 40 or 50 percent of this precipitation may be lost to evapotranspiration, a combination of evaporation from the soil and transpiration by plants, and up to 10 percent is converted to surface runoff that does not infiltrate.[1] This still leaves up to 50 percent or more of the precipitation to infiltrate the ground surface, either as shallow infiltration or as deep percolation reaching the water table. However, as impervious surfaces such as roads, rooftops, and parking lots have increased dramatically with development, water is prevented from penetrating the ground surface, the volume of runoff increases, and the volume of infiltration decreases.[2]

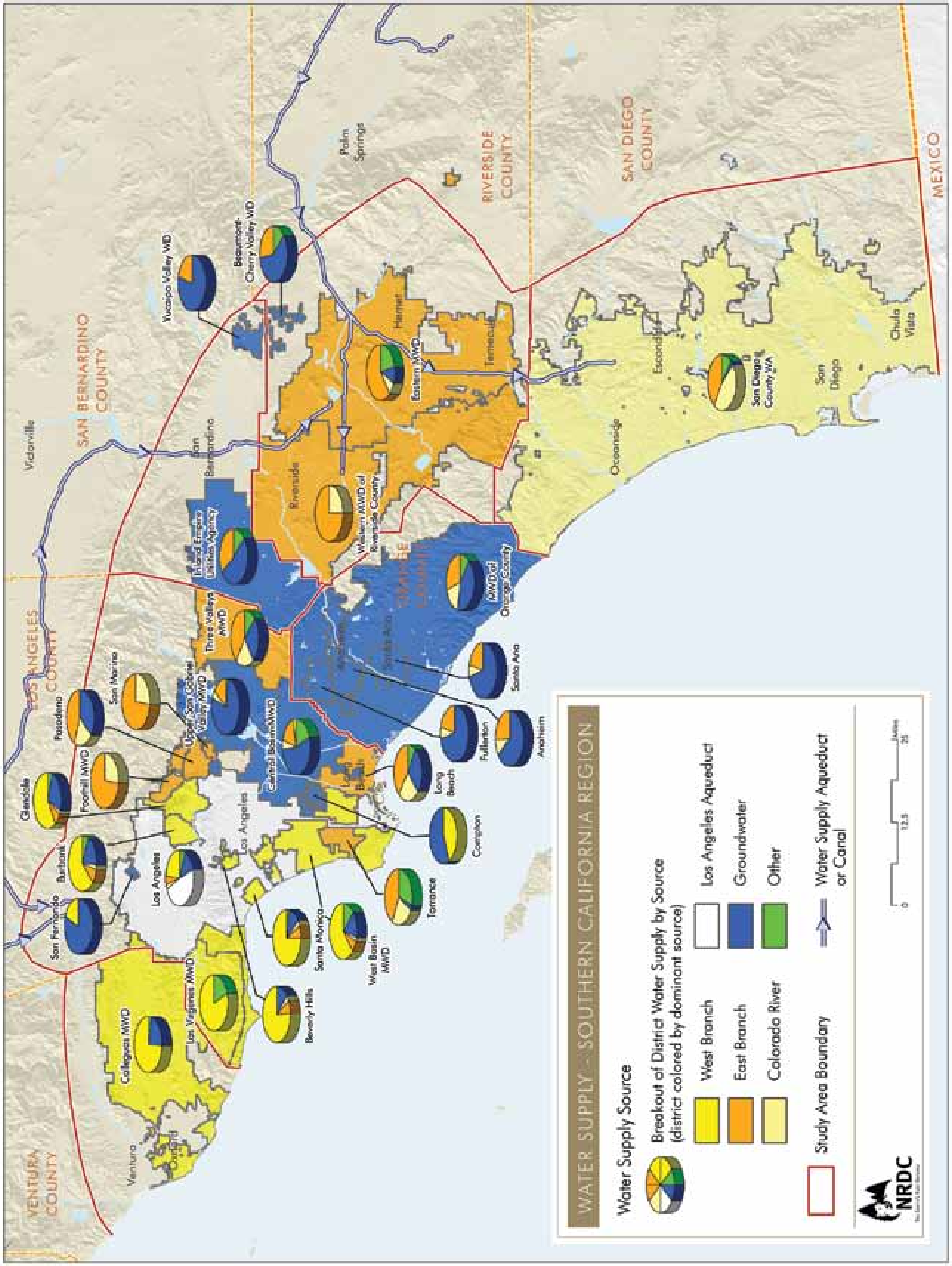
When impervious cover reaches 75 percent and above, as it does in many urban areas, it may result in more than a five-fold increase in surface runoff and a corresponding 70 percent drop in infiltration, with the greatest decrease seen in the quantity of water that percolates to sufficient depths to recharge groundwater.[3] LID practices that maximize infiltration allow for natural recharge to augment local supplies of water despite the effects of urbanization. A fundamental LID technique is amending native soils to increase their ability to absorb and store water for subsequent infiltration, which can broaden opportunities to employ infiltrative LID practices. LID techniques that promote capture of rainfall, used either to augment or in conjunction with infiltration practices, can also offer a significant opportunity to increase local water supplies where the natural hydrologic regime has been altered by development.

Groundwater Resources and Recharge in California

California is the nation's largest producer of groundwater, extracting nearly twice as much as the next state, Texas.[4] The average of 17 million acre-feet withdrawn in the state per year accounts for nearly 20 percent of all groundwater extracted in the United States annually.[5] Approximately 30 percent of California's urban and agricultural water needs are supplied by groundwater in an average year, a figure that rises to 40 percent or more during periods of drought.[6] As such, groundwater is rightfully called "one of California's greatest natural resources" and its continued supply is integral to California's environmental, economic, and social well-being.[7]

In southern California, groundwater has been used for over 150 years, and "the story of the growth of the region becomes the story of the utilization and application of its available waters."[8,9] Since settlers drilled the first groundwater wells, population has boomed, urban areas have sprawled, and the percentage of landscape covered with paved and impervious surfaces has expanded dramatically. This, in turn, has transformed the hydrologic regime that forms and replenishes groundwater upon which the region depends. Rainfall that would infiltrate the ground and recharge groundwater supplies under natural conditions is instead diverted and transported away by stormwater conveyance systems. Despite the diminishing recharge, groundwater continues to supply an average of 1.56 million acre-feet of water per year to the region.[10] Approximately 40 percent of the Metropolitan Water District of Southern California's (MWD) member agencies' water supply consists of groundwater in an average year.[11] Based on data from the most recent urban water management plans for each of the 26 member agencies located within the MWD service area, we created a map to illustrate the magnitude of southern California's dependence on groundwater supply. Each pie chart on the map in Figure 5 represents the overall water supply for an individual agency, with each sector of a chart indicating the percentage of water for that agency supplied from groundwater, the SWP, Colorado River, or other source. As the map illustrates, water agencies in a number of areas, including eastern Los Angeles, San Bernardino, and Orange counties, rely on groundwater as the principal source for municipal water supply. Even for the majority of those MWD agencies where groundwater is not the dominant source of water, it still forms a substantial percentage of the supply.

Figure 5: Water supply sources and classification for southern California (based on 2005 statistics)



Moreover, southern California is rich in groundwater potential, with a total estimated available basin capacity in MWD's service area of 3.2 million acre-feet.[12] Recharge of these basins is currently provided by imported water as well as local precipitation and runoff. Particularly where groundwater basins are currently or have historically been subject to overdraft (i.e., the amount of water withdrawn from the aquifer exceeds the amount of recharge it receives), such as the Chino Groundwater Basin or the Central and West Coast Groundwater basins on the coastal plain of Los Angeles, opportunities exist to restore natural hydrologic function that has been disrupted by development. Current trends are toward increased local rainwater recharge, and the LID strategies examined in this study would both follow and enhance this trend. Conditions for groundwater recharge are generally favorable throughout much of southern California, as soils underlying most of the region are highly permeable, allowing rapid infiltration into groundwater basins.

In the San Francisco Bay Area, groundwater plays a more limited, yet still vitally important role in ensuring the safe, sufficient supply of water to the region's population. For example, the Santa Clara Valley Water District, which provides water to 1.7 million Californians, has stated that "[g]roundwater is our most critical local asset for ensuring adequate water supplies now and in the future."[13,14] About one-half of the water used in Santa Clara County each year comes from local groundwater supply, and the Water District there considers it to be the region's "best protection against droughts."[15]

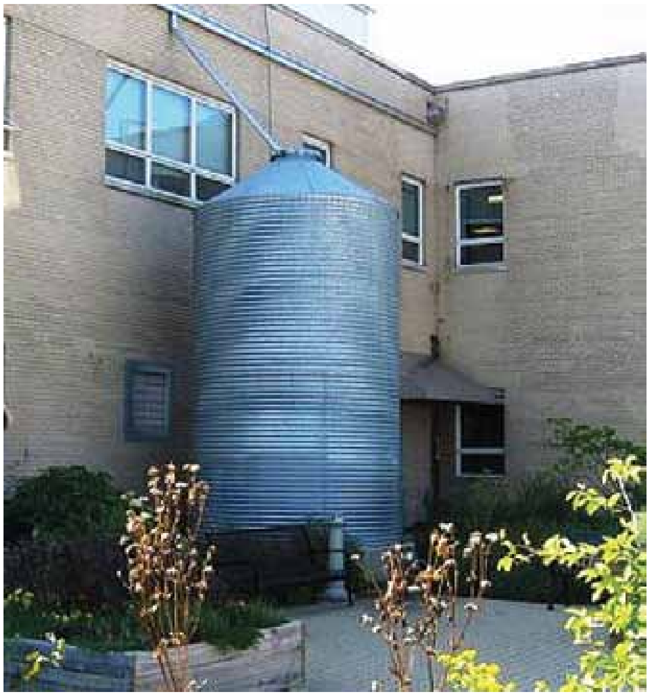
Groundwater recharge potential further exists in areas not traditionally viewed as having ideal conditions for infiltration. In the Los Angeles-Orange County coastal plain aquifer system contrasting layers of highly permeable gravels and finer-grained deposits that shape the region's hydrologic characteristics have resulted in large deposits of relatively shallow groundwater separated from the deeper, regional groundwater systems by the finer-grained deposits.[16] Generally, water managers have not utilized the shallow aquifers that characterize portions of the basin because of low yields, and in some places, poor water quality.[17] The increasing need for viable water supplies has begun to shift thinking on the potential for obtaining water from these aquifers. According to Ted Johnson, chief hydrogeologist at the Water Replenishment District of Southern California, the water has not generally been used for domestic or irrigation supply in recent years, "but it could be done... the water could be extracted and treated as needed for use... reverse osmosis may be needed if the water is too mineralized, or activated carbon if there is volatile organic contamination, but these technologies exist. There are entities pumping out shallow groundwater right now for dewatering purposes and we are looking at putting that water to beneficial use instead of losing it to the ocean."[18] All told, there is significant potential for LID practices that emphasize infiltration of stormwater to replenish water supply in this area.

Capture

Capturing rainfall for use onsite offers a similar opportunity to increase local supply of water and may be used where soils or surface conditions, such as the presence of shallow groundwater or groundwater contamination, are not highly amenable to infiltration or may be used concomitant with infiltration. For example, where development occurs over relatively impermeable soils or in densely developed urban environments, LID techniques favoring capture can "reduce annual runoff volumes by almost half to more than 3/4…with much of the water saved available for a beneficial use."[19] Water capture techniques are typically, though not exclusively, used to harvest rooftop runoff and can be applied at both large scale in commercial developments and residential subdivisions and at small scale using cisterns or rain barrels. Existing LID development has shown that capturing water is successful at reducing runoff discharged to storm drain systems and at conserving water for later use at all scales and under a variety of conditions. For example, the King Street Center in downtown Seattle uses water captured from roof runoff to supply over 60 percent of the building's toilet flushing and irrigation requirements, saving approximately 4.3 acre-feet of potable water per year.[20] On a smaller scale, the Carkeek Environmental Learning Center in Seattle drains rooftop runoff into a 3,500-gallon cistern to supply toilets.[21] As the average urban roof at a residential or commercial development accounts for 40 to 60 percent of the site's total impervious surface area (and therefore 40 to 60 percent of impervious surface runoff), vast quantities of water are available for harvesting to offset the need for other, more energy-intensive sources of water.

Regardless of the method used, there is tremendous potential throughout California to increase local water supply and reduce reliance on imported water or desalinated ocean water sources that generate considerable GHG emissions.

Rain barrel in Santa Monica, CA CREDIT: EPA/Abby Hall



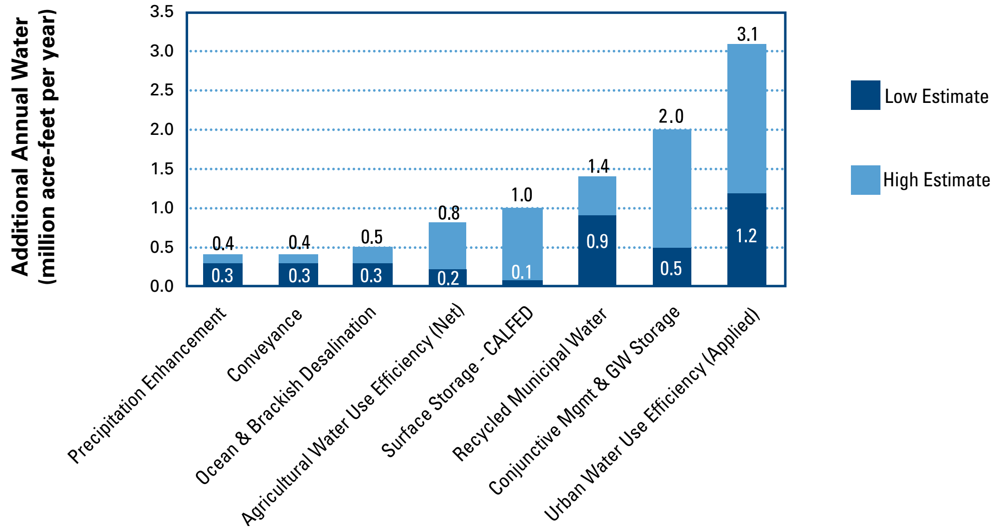
Cistern in Chicago CREDIT: EPA/Abby Hall

CHAPTER 3

WATER SUPPLY AND ENERGY IN CALIFORNIA

In California, water systems account for a staggering 19 percent of total electricity use and about 33 percent of non-power-plant natural gas use.[1] A significant portion of the electricity is used in the conveyance of water, which in California requires electricity inputs “substantially above the national average.”[2] Water is now recognized as one of the largest electricity users in California, and both the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have concluded that the energy embedded in water presents large, untapped opportunities for cost effectively improving energy efficiency and reducing GHG emissions.[3] Although the energy embodied in a unit of water varies with location and source, moving large quantities of water long distances and over mountain ranges, treating and distributing it within communities, water use and collecting and treating the resulting wastewater are each energy-intensive processes. Urban water use efficiency, groundwater management, and recycling or reuse have been identified by the Department of Water Resources (DWR) in its 2005 State Water Plan as the largest new water supply sources for the next quarter century. Capture presents an additionally significant opportunity to increase the energy-efficient supply of water. The following graph indicates the critical role these measures will play in California’s water future.

Figure 6. Water management and supply options for the next 25 years. From the California State Water Plan 2005, California Department of Water Resources, 2005.[4]



The Energy Intensity of Water in California

Importing Water

California's water systems are energy intensive due in part to the pumping requirements of major conveyance systems that move large volumes of water long distances and over thousands of feet in elevation. Certain interbasin transfer systems, such as California's SWP and the Colorado River Aqueduct (CRA), require large amounts of electrical energy to convey water.

Figure 7. Energy intensity of major water supply options in southern California. Robert Wilkinson, based on data from IEUA, West Basin MWD, DWR, and desalination estimates.

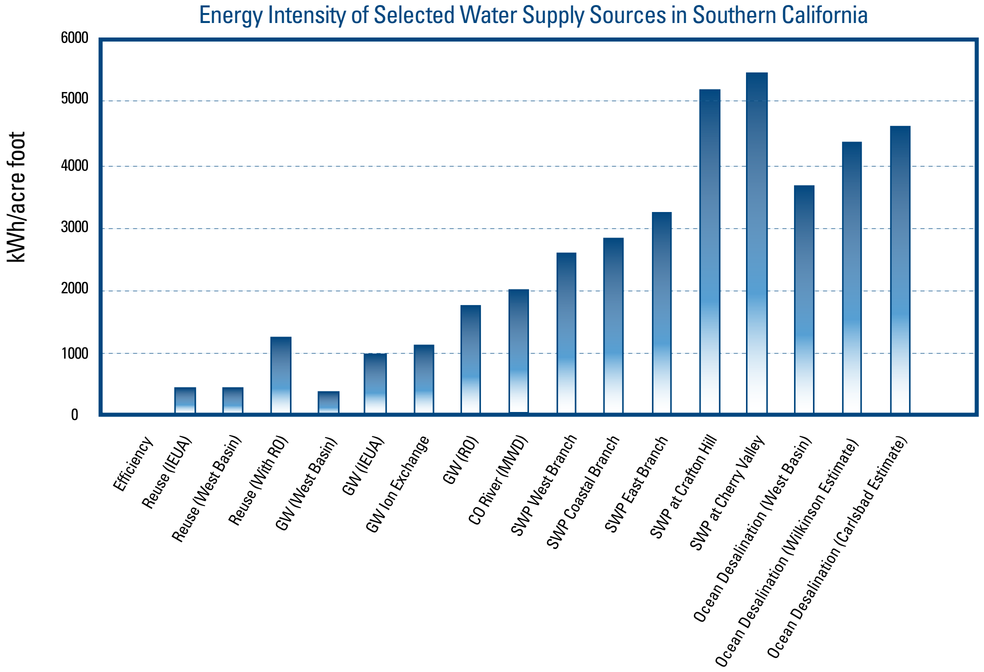


Figure 7 shows the energy intensity of major water supply options for inland and coastal locations in southern California. Each bar represents the energy intensity, expressed in kilowatt-hours per acre-foot, of a specific water supply source delivered at selected locations in southern California. Since water efficiency requires no energy inputs for pumping or treatment, it is shown as zero. For all other water resources, there are energy inputs that depend on many factors, including the quality of source water; the energy intensity of technologies used to treat the source water to quality standards for end users; the distance water needs to be transported to reach end users; and the efficiency of the conveyance, distribution, and treatment facilities and systems.[5]

Water pumping plants employed in the supply of imported water account for some of the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi Mountains, pumps water up 1,926 vertical feet, the highest single lift of any pumping plant in the world. It is the largest single user of electricity in the state.[6] In total, the SWP is the largest overall user of electricity in California.[7] Water use (based on embedded energy) is the second or third largest consumer of electricity in a southern California home after refrigerators and air conditioners,[8] and the electricity required to support water service in the typical home in southern California is estimated to be 14–19 percent of total residential energy demand.[9]

Figure 8. State Water Project Energy Inputs and Recover . Robert Wilkinson, based on data from California Department of Water Resources. (kilowatt-hours per acre-foot pumped—includes energy recovery)

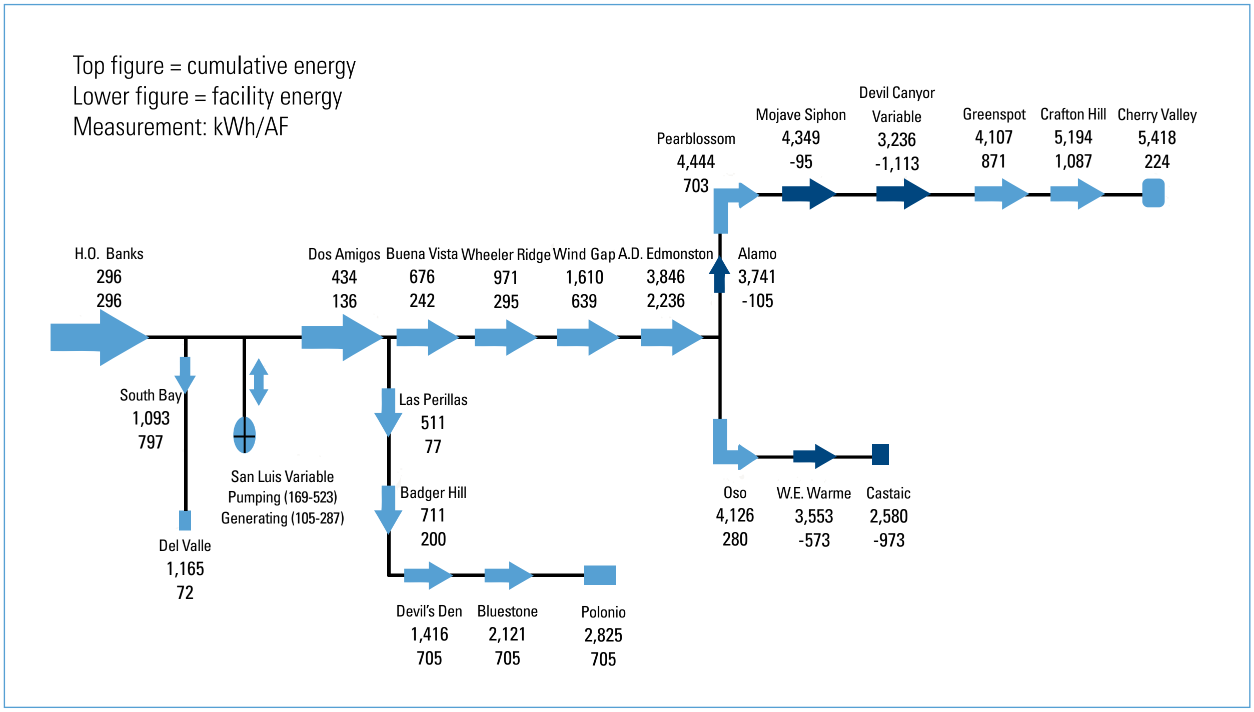


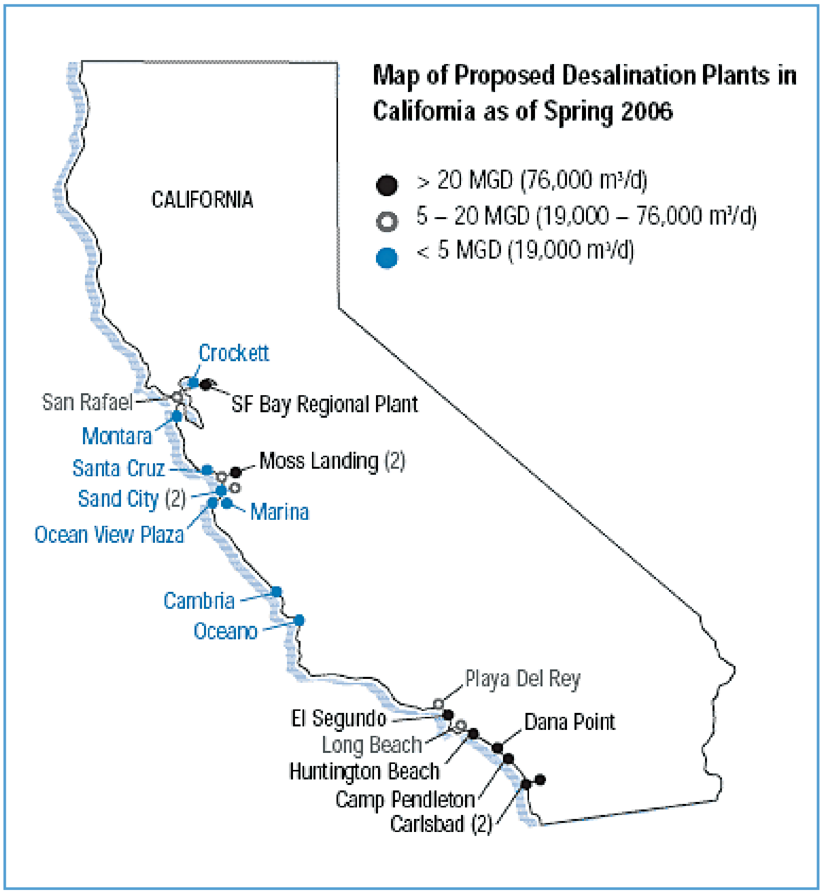
Figure 8 shows the cumulative net energy requirements and the incremental energy inputs or outputs at each of the pumping and energy recovery facilities of the SWP. Energy recovery is indicated with negative numbers, which reduce net energy at that point in the system.

As shown in Figure 8, approximately 2,580 kWh are required to pump one acre-foot of SWP water from the Sacramento-San Joaquin Delta to Castaic on the West Branch of the SWP; 3,236 kWh/af are required to reach the Devil's Canyon Power Plant on the East Branch.[10] Additionally, approximately 2,000 kWh/af are required to pump Colorado River water to southern California.[11] The water from these systems is delivered raw (untreated) to those points. From there, conveyance continues by gravity or pumping to treatment and distribution systems within individual service areas. In general, service areas at higher elevations have higher energy requirements. Thus, at Cherry Valley and other locations near the terminus of the East Branch, the energy intensity required for raw water supply is as high as 5,418 kWh/af.

Ocean Desalination

Twenty individual seawater desalination plants have been proposed for operation in California. Four plants, with a combined maximum proposed capacity of more than 100,000 acre-feet per year, have been proposed in the San Francisco Bay area alone.

Figure 9. Planned seawater desalination plants as of 2006 (Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006).[12]



Whereas ocean desalination is being pursued as a potential measure for supplying additional water, environmental and cost concerns regarding the desalination process remain controversial. Pacific Ocean salinity is 34–38 grams/Liter (g/L), while brackish water contains 0.5–3.0 g/L. Potable water salt levels should be below 0.5 g/l. Using existing technologies to reduce salt levels from over 30 g/L to 0.5 g/L and lower (to meet drinking water standards) requires considerable amounts of energy for the pressure to drive water through extremely fine filters in the process of reverse osmosis (RO). (All of the desalination facilities proposed in California utilize RO technology.) As a result, ocean desalination requires an estimated 4,400 kWh/af to supply potable water. Improvements in desalination technology have lessened the amount of pumping energy required for this process, but high energy intensity is still an issue. Furthermore, the seawater intake process for many coastal plants raises significant ecological concerns, as impingement and entrainment can result in the deaths of large numbers of aquatic organisms, including fish, invertebrates, and their eggs and larvae.[13] Disposal of highly concentrated brine resulting from the RO process also remains a concern.

Groundwater Recharge and Capture

Next to efficiency, recycled water and groundwater are lower energy-intensive options than other marginal (e.g., new) water resources in most heavily populated areas of California.[14] Even with advanced treatment to remove salts and other contaminants, recycled water and groundwater (the Reuse and GW columns in Figure 7) usually require far less energy than imported water (CO River and SWP) and seawater desalination (Desal), as does capture and onsite use. For example, even the Chino desalter, which uses an RO treatment process to provide high-quality potable water by removing dissolved solids such as salt from impaired groundwater in the inland Chino groundwater basin (GW (RO) in Figure 7), is far less energy intensive than any of the imported sources. From an energy standpoint, greater reliance on LID practices that emphasize groundwater recharge and capture provides considerable benefits. These energy benefits also include significant potential GHG emissions reductions.

Groundwater pumping energy requirements vary depending on the lift required. As illustrated in Figure 7, the energy required to produce groundwater in the West Basin municipal water district is approximately 350 kWh/af, while in the Inland Empire groundwater production requires 950 kWh/af. In the City of Los Angeles, groundwater requires 580 kWh/af to produce.[15] Analysis of different sources provides a reasonably consistent finding: local groundwater is less energy intensive than imported water from the SWP, CRA, or ocean desalination.

Increasing the availability of energy-efficient, local water supply could therefore result in a savings for individual end users and an overall reduction in the energy required to supply water.

Figure 10. Energy intensity of marginal water supply sources in Southern California by area

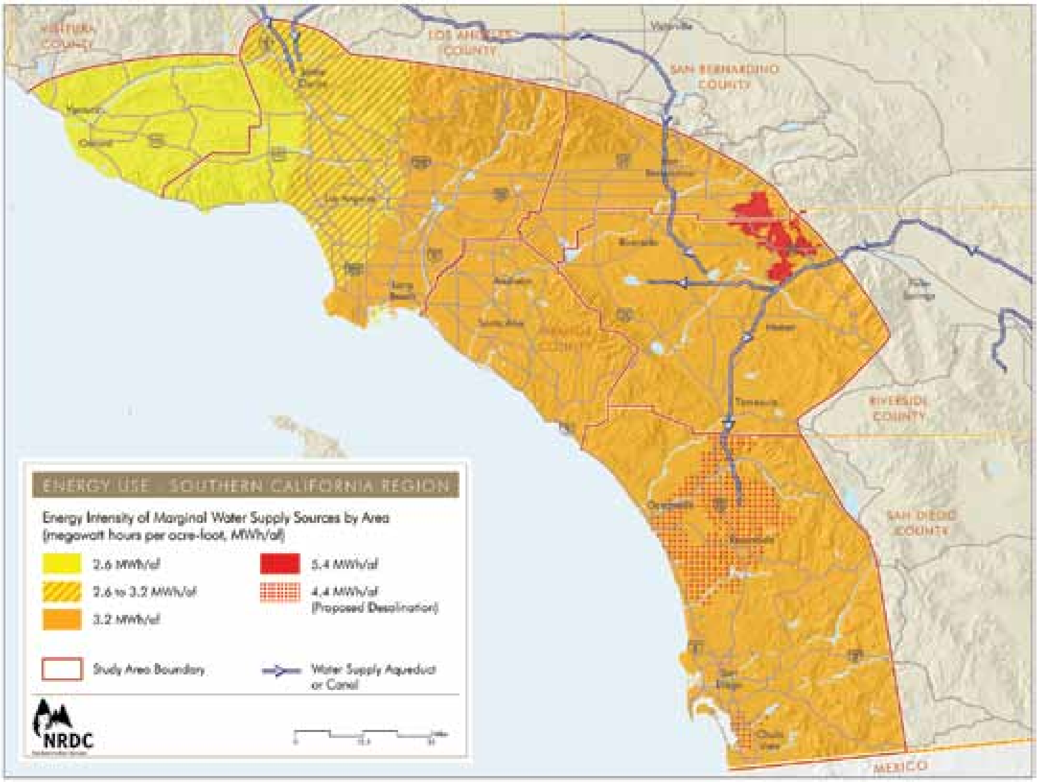


Figure 10 shows the energy intensity of marginal water supply in southern California, based on our review of water supplies and corresponding energy requirements for water sources. In all of these areas, the increased use of groundwater or of water captured from rooftop runoff can be used to offset the more energy-intensive water supply.

CHAPTER 4

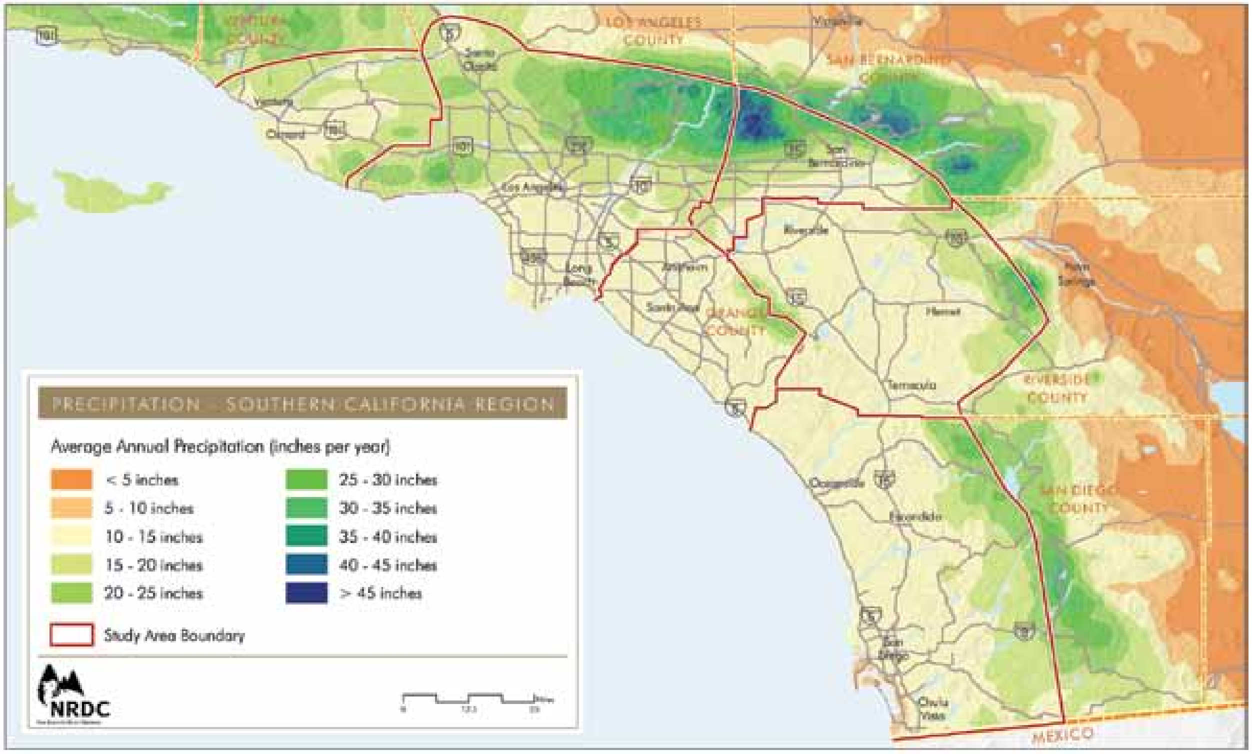
THE POTENTIAL FOR LOW IMPACT DEVELOPMENT IN CALIFORNIA

We analyzed land use, water supply patterns, and the energy consumption of water systems in order to determine the benefits of LID, including: 1) the volume of additional water supply that could be provided through the implementation of LID practices; 2) the resulting savings of energy due to increased availability of local water supply; and 3) the associated reduction of GHG emissions. Our study represents one of the first attempts to quantify the water supply benefits of LID on a regional basis by using large-scale, GIS-based land use data. Further, it quantifies the connection between the energy intensity of water supply and LID water management practices that can serve to reduce energy use. In this section, we discuss the details of our analysis, as well as study parameters and the assumptions made in quantifying the water, energy, and GHG emissions reduction benefits that can be derived from LID.

Selection of Study Areas

In order to assess LID's potential for water and energy benefits and emissions reductions, the study focused on coastal areas of urbanized southern California and the San Francisco Bay area. These regions represent the two most heavily urbanized and developed regions of California and incorporate the majority of the state's population—approximately 50 percent of the state's residents live in the counties located within the southern California study area and an additional 20 percent live in the San Francisco Bay region.[1] The study areas include a wide range of energy use per unit of water delivered. Imported water accounts for roughly half of urban water supply in the southern California region, with energy inputs requiring between 2,000 kWh (Colorado Aqueduct) and 5,418 kWh (SWP at the terminus of the East Branch) per acre-foot delivered. (See Figures 5 and 10 detailing marginal supply of energy from imported sources.) The San Francisco Bay region, which relies heavily on imported surface water, is the site of four proposed ocean desalination plants with an estimated capacity of between 35,800 and 108,700 af/year and an embedded energy requirement of an estimated 4,400 kWh/af.[2,3] Rainfall averages roughly 10 to 15 inches annually in most portions of the southern California study area (Figure 11) and from 18 to more than 30 inches annually in the San Francisco Bay region.[4] These areas are projected to see substantial population growth accompanied by development that could implement LID practices to maximize groundwater recharge and/or rainfall capture.

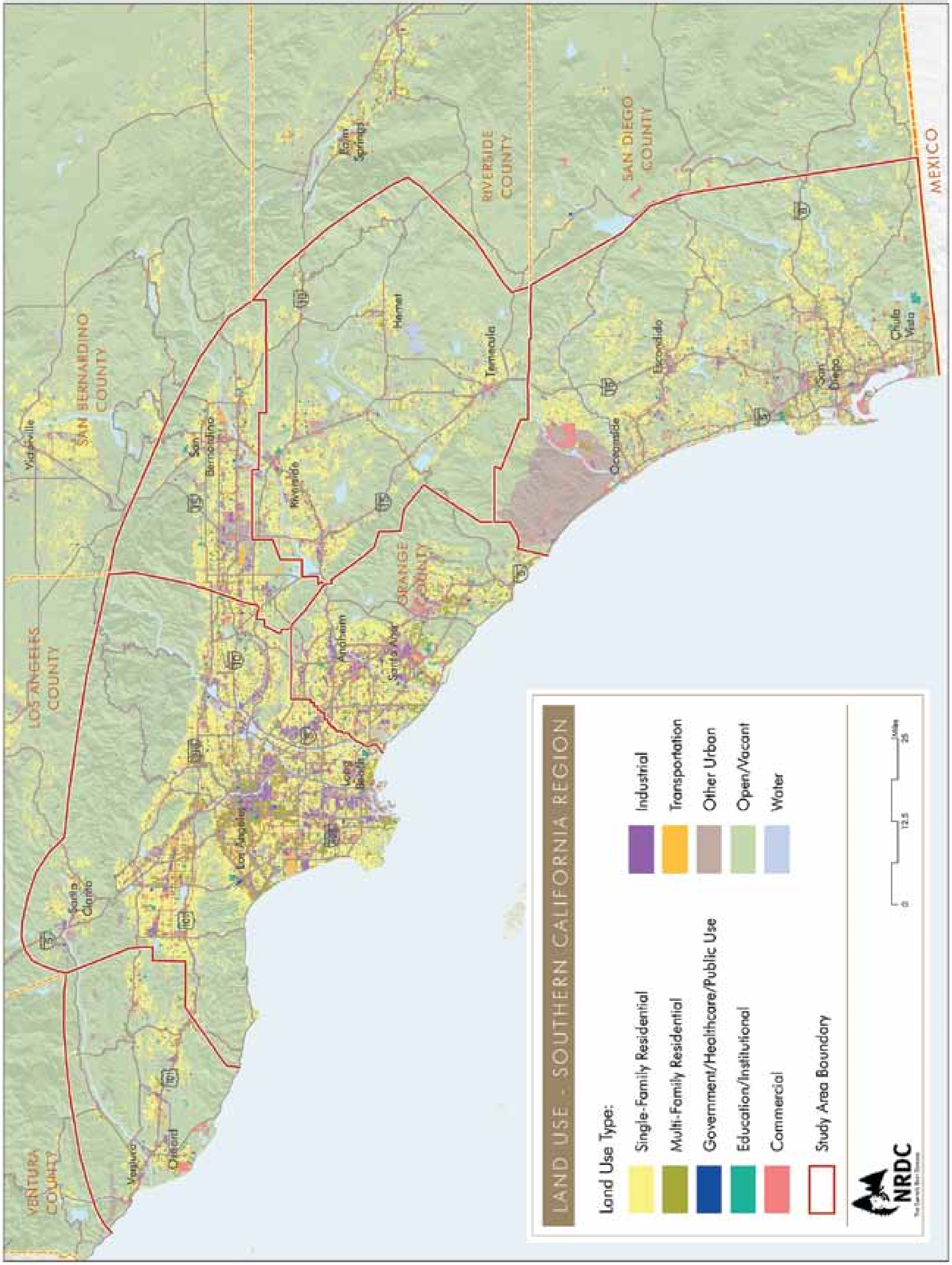
Figure 11. Precipitation map of urbanized southern California (based on NRCS PRISM average annual precipitation, 1961-1990)



Coastal Urban Southern California

The southern California study area includes San Diego County, Orange County, and portions of Ventura, Los Angeles, San Bernardino, and Riverside counties (Figure 12). The study area is loosely defined by the Topatopa Mountains to the northwest, the San Gabriel Mountains and San Bernardino Mountains (which form a border between the greater Los Angeles area and San Bernardino and the Mojave desert) to the north, and the San Jacinto Mountains to the east.

Figure 12. Map of land use within the southern California study area (based on SCAG 2005 and SANDAG 2007 land use data sets)



San Francisco Bay Region

The San Francisco Bay region study area includes all or portions of San Francisco, Marin, Contra Costa, Alameda, Santa Clara, and San Mateo counties (Figure 12).

Seawater desalination plants have been proposed to supplement water supply in areas serviced by agencies including Marin County, the East Bay Municipal Utilities District, Contra Costa Water Agency, San Francisco Public Utilities Commission, and Santa Clara Valley Water District. Because ocean desalination has not yet been proposed for supply in Sonoma, Napa, and Solano Counties, we do not include these areas in our analysis, though substantial opportunities to increase local water supply through groundwater recharge and capture do exist in these areas.

Figure 13. Map of land use within the San Francisco Bay study area (based on ABAG 2006 planned land use data set)

Results

Our analysis found that LID has a substantial potential to save both water and energy in California. In just the urbanized areas of southern California and limited portions of the San Francisco Bay area, LID could provide 229,000–405,000 acre-feet of water per year by 2030, with a corresponding annual electricity savings of 573,000–1,225,500 megawatt-hours and a reduction of 250,500–535,500 metric tons of CO_2.[5] The wide ranges of potential water supply, energy, and GHG reductions reflect a set of variables and input values that include low, medium, and high estimates. These figures will increase with continued development and redevelopment after 2030. As much as an additional 75,000 acre-feet of water could be saved annually by 2030 through implementing LID practices at new industrial, government and public use, and transportation development or redevelopment in southern California alone.

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION WATER SAVINGS—2030
(Acre-feet per year, af/yr)

	Southern California	San Francisco Bay	TOTAL
Low	194,500	34,500	229,000
Medium	265,500	49,000	314,500
High	342,000	63,000	405,000

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION ENERGY SAVINGS—2030
(Megawatt-hours per year, MWh/yr)

	Southern California	San Francisco Bay	TOTAL
Low	443,500	129,500	573,000
Medium	676,500	190,500	867,000
High	974,500	251,000	1,225,500

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION CO_2 SAVINGS—2030
(Metric tons per year)

	Southern California	San Francisco Bay	TOTAL
Low	194,000	56,500	250,500
Medium	295,500	83,500	379,000
High	426,000	109,500	535,500

Methodology

The volume of water, associated energy savings, GHG emissions reductions were calculated based on analyses of urbanized southern California and portions of the San Francisco Bay area. Though LID practices are ultimately applicable to any land use or development type, we focused our initial analysis on commercial and residential development because of data availability regarding future new development and redevelopment rates, as discussed below.

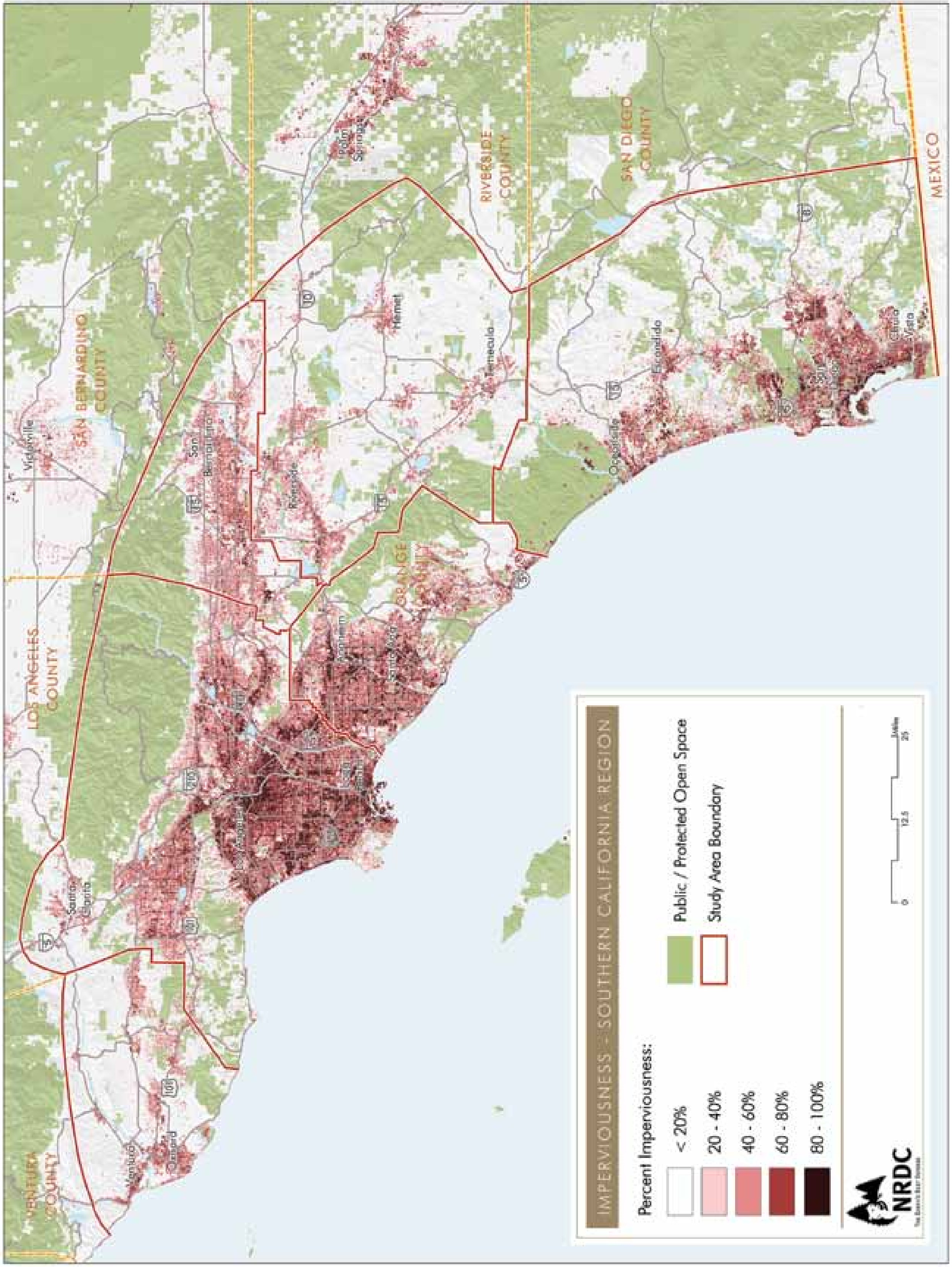
Energy savings are calculated based on current and projected marginal water supply sources in each area. Although individual water suppliers will determine what source to take less of for supply if it is not required (for example, if additional water were to become available through use of LID practices), in general, suppliers will reduce supply of the most expensive source, which in California is usually the most energy intensive. Imported water and ocean desalination would be the sources for which demand would be reduced, and we compare the energy required to augment water supplies through LID to these marginal sources. The difference between energy requirements for LID applications (groundwater pumping, onsite capture and use, treatment, etc.) and current marginal water supplies (SWP, desalinated ocean water) is the basis for the calculations.

Land Use Analysis and Impervious Surface Cover

After establishing the study area boundaries, we conducted a GIS-based land use study of each area, broken down by county, to determine the total area occupied by each land use type—e.g., single-family residential home, high-rise office building, park and ride lot, etc.[6] We selected land use types characterized by "urban" density, having greater than 20 percent impervious surface cover over contiguous areas, or for residential purposes, having greater than two single-family residential structures per acre. For each land use category we calculated the percentage of surface area covered by roads or streets. We then subtracted this area from the identified land use category in order to designate municipal road construction as a separate land use type for analysis of runoff.

Based on GIS analysis, we calculated the average percent of impervious surface cover and average annual precipitation for each land use type. We used these values to determine the total volume of rain falling over impervious surface for each land use category. For each identified land use type, we further subdivided our analysis to separately evaluate different land use subgroups based on: 1) those with moderate (less than 85 percent) impervious surface cover overlying soils with generally adequate infiltrative capacity; or 2) those for which capture may represent the preferred means of harvesting water, such as those characterized by high impervious surface area (greater than 85 percent impervious surface) or by D-soils that may exhibit decreased infiltrative capacity.

Figure 14. Map of impervious surface cover within the southern California study area (based on NLCD 2001 impervious surface data set)



Runoff Volume

We evaluated land use data for all commercial and residential development within both study areas, as well as separately for industrial, government and public use, and transportation development in southern California, and determined the average percentage of impervious surface for each designated land use type. (See Figure 14, map of impervious surface in southern California. Note the increased impervious coverage in areas such as downtown Los Angeles, Santa Monica, and San Diego.) Impervious surface runoff from development at all land use types was calculated based on average rainfall compiled from the NRCS 1961–1990 data set and averaged across each of the designated land uses to determine the total volume of annual impervious surface runoff from the current distribution of specified land use types within the study area.[7] Runoff from paved and other nonroof surfaces was calculated based on a runoff coefficient for impervious areas of $C = (0.009) * I + 0.05$, where I is the impervious percentage (with $I = 100$ percent for fully impervious areas).[8] This is essentially equivalent to 95 percent of precipitation falling on paved surfaces mobilizing as runoff.

For calculating rooftop runoff directed to capture and use, our analysis assumed a runoff coefficient for rooftop surfaces of $C = 0.9$, meaning 90 percent of rainfall on roof surfaces will occur as runoff available for capture and use. Runoff coefficients for rooftop surfaces are generally estimated to vary between 0.75 and 0.95, reflecting differences in how materials, slope, and other variables of rooftop construction may affect runoff.[9] Stormwater management agencies in California commonly differ in their selection of runoff coefficients. For example, the City of Salinas bases rooftop runoff on a coefficient of 1.0, whereas the Santa Clara Valley Urban Runoff Pollution Prevention Program bases runoff at the low end of generally accepted values, using a coefficient of 0.75.[10,11] However, many architectural and engineering experts treat rooftop runoff as occurring at the higher end of the accepted range, stating for example, "a built-up roof is considered to have a runoff coefficient of 0.95; in other words, about 95 percent of the water hitting a conventional roof will leave the surface and needs to be accounted for in the design of the building's storm-water system" and many states and municipalities use a coefficient of 0.9 to determine runoff volumes from rooftop surfaces.[12,13] As a result, we find a coefficient of 0.9 to represent a reasonable estimate for rooftop-runoff collection potential.

In addition to precipitation-based runoff, dry-weather runoff stemming from human activities, such as landscape irrigation and car washing, was calculated within the southern California study area and Santa Clara portion of the San Francisco Bay study area. Dry-weather runoff was calculated based on a figure of 0.152 gallons per acre of pervious surface per minute for residential and commercial land use types likely to include landscaped cover. This figure was derived from the "Residential Runoff Reduction Study" performed by the Irvine Ranch Water District and extrapolated to include commercial development for our study.[14]

Recharge

Land use and impervious surface runoff totals were calculated based on the underlying soil type from a combination of U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic (NRCS SSURGO) soil data and State Soil Geographic (STATSGO) soil data in order to determine infiltrative capacity of soil underlying each land use type. Areas were categorized as having soils in NRCS Hydrologic Soil Group A, B, C, or D, which refer to "soils grouped according to their runoff potential" and the soils' infiltrative capacity.[15] Where infiltration and groundwater recharge was selected as the preferred method for increasing local supply, such as for development with less than 85 percent impervious surface cover occurring over A, B, or C type soils, the study assumes that with adequate conditions capacity exists to infiltrate 100 percent of the impervious surface runoff generated at a given site, less the portion of runoff lost to evapotranspiration.

Selection of Infiltration vs. Capture

For the purposes of this study, where impervious surface runoff occurred over areas characterized as having D soils, capture of rooftop runoff, rather than groundwater recharge, was selected as the method for increasing local water supply and reducing energy use. While local variation is likely to allow for some groundwater recharge to occur in many locations underlain by D soils, we uniformly based our model on capture in these circumstances to simplify the model parameters. Water from rooftop runoff was also used as the primary basis for calculating the potential water savings in areas of high impervious surface cover, defined as areas greater than 10 acres in size and containing contiguous impervious cover of greater than 85 percent (e.g., downtown Los Angeles, which is characterized by high percentage of impervious cover). Though these areas may encompass sufficient pervious cover to infiltrate a large percentage, if not the total volume of associated impervious surface runoff, we assumed a conservative bias in characterizing the potential opportunities for groundwater recharge and selected capture as the preferred method, with only limited use of infiltration, under these conditions. We recognize as well that site-specific conditions that do not favor infiltration may exist, such as the presence of shallow groundwater that could pose a liquefaction hazard or already require dewatering, as well as the existence of groundwater contamination.[16] In order to address this possibility, certain of our model scenarios employ capture as the principal means of augmenting water supply for large portions of the southern California study area (see section on Assumptions and Variables, below).

Finally, for all areas of the San Francisco Bay area other than the Santa Clara Valley, where extensive groundwater production does occur, we selected rooftop runoff as the preferred means of increasing local supply. Although opportunities for infiltration exist throughout the Bay area, outside of Santa Clara County and some other smaller regions, groundwater currently accounts for only about five percent (or 68,000 af/year) of the region's average annual water supply.[17] As a result, capture may provide greater opportunity to immediately increase local water supplies (and consequently, reduce energy consumption) on a wide scale.

Development and Redevelopment: New Construction and Changes to the Existing Built Environment.

Water supplies generated by LID for 2030 were calculated based on projected commercial and residential development rates for each county included within the study area (using commercial development rates as a proxy for industrial, government and public use, and transportation development). Development projections were provided by the Southern California Area Governments, San Diego Association of Governments, Association of Bay Area Governments, California Department of Finance, and national-scale land use data.[18,19,20,21,22] Redevelopment rates were calculated based on an annual national "loss rate" of 1.37 percent for commercial buildings and 0.63 percent for residential structures.[23] These numbers are likely conservative, as the rate of development in the selected study areas exceeds national rates. This is particularly the case because the report forming the basis for loss estimates states that, "In 2030, about half of the buildings in which Americans live, work, and shop will have been built after 2000."[24] However, based on these estimates, our study assumes that 100 percent of future development and redevelopment at each land use type would be constructed using LID practices.

Reduction in Energy Use for Water Supply

Energy savings were calculated based on reducing the volume of supply from the marginal, or highest, energy-intensive source of water for each area. Within the southern California study area, SWP imports and projected ocean desalination are the marginal or most energy-intensive water supply sources (though for the purposes of this study we used only water from the SWP for calculating the marginal source in southern California). Projected use of ocean desalination water in the San Francisco Bay area is the marginal or most energy-intensive source in the San Francisco Bay study area. In each instance, the volume of imported or ocean desalination water to be offset was calculated based on the volume of water estimated to be either infiltrated for groundwater recharge or harvested through use of LID practices. In southern California, the marginal water source was determined based on a review of water agency Urban Water Management Plans. The marginal source was determined to be the West Branch of the State Water Project for Ventura and the western half of Los Angeles County; and the East Branch of the State Water Project for the eastern half of Los Angeles, Orange, San Bernardino, Riverside, and San Diego counties. Energy savings were calculated by determining the total amount of water to be recharged or captured within the study area, then calculating the energy required to treat and supply the same volume of water through the marginal supply source, less the energy required to supply the volume of water through either groundwater pumping or rainwater use.

GHG Conversion Factor

Estimated reductions in GHG emissions were calculated based upon a conversion factor established by the California Air Resources Board for climate change measures to reduce electricity and natural gas use in California. The reductions in GHG emissions are based on reduction of in-state natural gas electricity generation, with an emission factor of 4.37x10-7 MMTCO2E/MWh (963 lbsCO2E/MWh).[25] This is equal to 0.437 metric tons of carbon dioxide equivalent per MWh.

Conservative Bias in Assumptions

We note that the overall estimates for both water savings and resultant energy savings presented here are conservative. The analysis includes only a subset of the urban areas within California, as detailed above, and assumes a cautious figure for future development rates for these areas. Within the subset of commercial and residential development analyzed, the study does not incorporate the vast majority of existing development that could be retrofitted using LID practices. The analysis includes only new and redeveloped properties with a lesser percentage of retrofitted structures, while excluding the remaining built environment. For example, in the portion of Los Angeles County located within the study area, there were more than 540,000 acres of development as of 2005 in the land use categories selected for analysis. The study considers in its highest estimate that, by 2030, only approximately 135,000 of these developed acres will undergo redevelopment or retrofitting to incorporate LID practices, leaving 75 percent of the existing built environment (as of 2005) outside of the study's parameters. As stated earlier, the estimates incorporate only commercial and residential development and do not consider the potential water and energy savings available from implementation of LID practices at industrial, government and public use, and transportation development or redevelopment. These land use types cover more than 100,000 acres within the southern California study area, adding a substantial area of impervious surface and corresponding runoff not included in the current analysis.

Finally, the estimates do not take into account the loss rates for water supplied through the State Water Project, Colorado River Aqueduct, or local distribution systems. These systems lose a portion of the total water conveyed through a combination of evaporation and leakage during the course of transport, and the additional energy required to transport or pump this water has not been factored into the above calculations. As a result, and given the additional opportunities for implementation of LID practices not considered by our analysis, these findings should be considered to be conservative estimates of the total savings that would result from implementation of LID statewide.

Assumptions and Variables in Estimates of Water and Energy Savings Due to LID

Following from the above methodology, we developed low, medium, and high savings estimates for the potential water, energy, and GHG emissions savings that LID can produce with implementation at new development and redevelopment within the study areas. This range reflects the unknowns and potential variability of individual factors that may affect water harvesting through both infiltrative and capture practices, as well as the energy requirements of local supply.

Within this framework, we have considered the following factors in developing the estimates of water and energy savings. For each factor, we present the range of values used to calculate our low, medium, and high savings estimates. For a complete discussion of the parameters of each variable, including data sources, see Appendix A: [26]

- Percentage of runoff directed to infiltration and groundwater recharge but lost to evapotranspiration: For the study estimates, we base the estimated loss of groundwater recharge due to evapotranspiration on studies being conducted by the Los Angeles-San Gabriel Rivers Watershed Council, at a range of between 10 and 30 percent of total runoff generated.[27]

- Percentage of impervious surface comprised of rooftop: In six different case studies of southern California building permits, rooftop surface averaged between approximately 40 percent and 60 percent of total impervious surface area.[28]

- Percentage of retrofitted development employing LID principles: For properties that will undergo a substantial retrofit or redesign that does not include a complete rebuild or reconstruction of existing structures, we assume a construction rate equal to the overall redevelopment within each study area, but that only 25 to 50 percent of these retrofits will employ LID practices.[29]

- Energy required for extraction of infiltrated water by groundwater pumping: We base our energy requirements for water supplied through groundwater pumping on the range of energy intensity of groundwater supply that exists between groundwater sources for the West Basin Municipal Water District (350 kWh/af) and Inland Empire Utilities Agency (950 kWh/af). (See Figure 7.)

- Energy required for capture and use of rooftop water: As with groundwater production, a range of potential energy requirements exists in order to use water from rooftop capture, though it may require essentially no energy for low-volume, nonpressurized systems at single-family residences. We base our energy requirements for rooftop capture on an average of 186 kWh/af for use of drip-based irrigation in our high estimate and 338 kWh/af for sprinkler-based irrigation systems in our low estimate.[30]

- Percentage of roads to be developed as green streets: The study assumes that 50–80 percent of streets constructed in areas of new development and 25–50 percent of streets corresponding to redevelopment will be green streets.

- Local variation in groundwater conditions and infiltrative capacity: As a final variable, we recognize that there may be areas, such as those overlying shallow or contaminated groundwater, that we have initially identified as having the greatest potential savings available through infiltration, for which capture may ultimately prove to be a preferred method for augmenting water supply (these areas represent land use over and above those areas designated as having a high percentage of impervious surface or as underlain by D soils). In order to address this possibility, we assume for our low and medium savings estimates that up to 50 percent of Los Angeles County within the study area will augment water supplies through practices emphasizing use of capture rather than infiltration.

Given the framework within which we have considered these variables, we regard even our high savings estimate to be a reasonable calculation of the real-world savings that LID practices can achieve in California. Under these scenarios, and in light of the assumptions made in calculating each estimate, it can be seen that the ratio of energy saved per unit of water increases significantly from the low-end estimate (2,502 kWh saved per acre-foot) to the high-end estimate (3,025 kWh saved per acre-foot). This difference results from the lower requirements of energy supply for groundwater or capture assumed in the high savings estimate, which we consider to more accurately reflect likely real-world conditions overall. However, and regardless of the difference in total water savings, total energy savings, or energy saved per unit of water, the results compel the same conclusion to be drawn—the use of LID presents a significant and currently untapped opportunity to reduce the use of energy required to supply water in California or other regions reliant on energy-intensive sources of water.

Conclusion

LID offers important opportunities to tackle climate change and its impacts on California, while simultaneously addressing vital issues of water quality and quantity. California, and other states in similar circumstances, must act rapidly to reduce global warming pollution. LID, by reducing the need to rely on energy-intensive sources of water, should be aggressively implemented. Indeed, our research has demonstrated that significant opportunities for increasing water supply while reducing the energy used to supply water exist at a wide variety of development types, in many different geographic locations. Given the multiple benefits LID provides and the robust contributions its use can make to reducing GHG emissions, LID practices that emphasize water harvesting should be required for dischargers throughout California and in other jurisdictions where the energy and GHG intensity of water supply may be reduced by augmenting local groundwater or capturing runoff.

APPENDIX A
ASSUMPTIONS AND VARIABLES FOR LID QUANTIFICATION

- Percentage of runoff directed to infiltration and groundwater recharge but lost to evapotranspiration: A part of the Water Augmentation Study conducted by the Los Angeles and San Gabriel Rivers Watershed Council (LASGRWC) and partners based on the Ground Water Augmentation Model—a soil-moisture accounting model created by the U.S. Bureau of Reclamation—estimates that the evapotranspiration loss of water retained for onsite infiltration and groundwater recharge is minimal across various soil types and development patterns, often on the order of only 10 percent of the retained flow. For the most conservative savings estimate, we assumed that 30 percent of the water infiltrated onsite will be lost through evapotranspiration (reflecting a situation closer to predevelopment conditions, in which 40 to 50 percent of water may be lost). For our middle estimate, we have assumed a 20-percent loss rate, and for the high savings estimate, a 10-percent loss rate.

- Percentage of roads to be developed as green streets: Surface roads and sidewalks account for as much as 20 percent of the total impervious cover in residential and commercial developments within the study area. Using "green streets," or streetscapes designed according to LID principles, can significantly increase the volume of water available to augment local water supply through infiltration and recharge. While broad data were not available on the rate of green street development in California, we have assumed in our low-end savings estimate that 50 percent of roads constructed in areas of new development will be engineered according to LID principles. In the medium estimate, we assume that 65 percent of roads in areas of new development and 25 percent of roads in areas of redevelopment will be engineered or resurfaced according to LID principles. In the high savings estimate, we assume that 80 percent of roads in areas of new development and 50 percent of roads in areas of redevelopment will be engineered using LID principles.

- Percentage of retrofitted development employing LID principles: In addition to calculating a rate of redevelopment within the study areas, we include an estimate for properties that will undergo a substantial retrofit or redesign that does not include a complete rebuild or reconstruction of existing structures. We have assumed the rate of retrofitting of existing development to occur at the same rate as overall redevelopment within each of the study areas. In the low-end savings estimate, however, we assume that only 25 percent of these structures will employ LID practices, while in the medium- and high-end savings estimates we assume that 50 percent of the retrofitted structures are re-engineered to incorporate LID practices.

- Percentage of impervious surface comprised of rooftop: The percentage of impervious cover present as rooftop surface area at any individual site varies significantly. However, an analysis of six different case studies of building permits in southern California found that rooftop surface averaged between approximately 40 percent and 60 percent of total impervious surface area at a given site.[1] As a result, our low-end savings estimate assumes that water harvesting will occur from 40 percent of the impervious surface area onsite, the medium estimate assumes a 50 percent rooftop scenario, and the high savings estimate assumes 60 percent of impervious surface as rooftop area.

- Energy required for extraction of infiltrated water by groundwater pumping: The energy required to pump and produce potable water through groundwater supply is determined by numerous factors, including depth to groundwater, pump and motor efficiency, and other variables. Energy requirements for treatment are impacted by the presence of salts or other contaminants that may require treatment. Thus, uncertainty exists in calculating the specific energy requirements for augmenting water supply through groundwater recharge. Whereas pumping and treating groundwater in areas such as the West Basin require only a few hundred kWh/af, groundwater production may require greater than 1,500 kWh/af in the Chino Basin because of use of reverse osmosis. To be conservative, we have assumed a moderate-to-high overall embedded energy requirement for groundwater production. For the low savings estimate, we use the energy required to produce groundwater for the Inland Empire Utilities Agency (950 kWh/af, see Figure 7); for the middle estimate, the energy required to produce groundwater in Los Angeles (580 kWh/af); and for the high savings estimate, the energy required in the West Basin Municipal Water District (350 kWh/af).[2]

- Energy required for capture and use of rooftop water: As with groundwater production, a range of potential energy requirements exists in order to provide water through rooftop capture. We have reviewed a variety of rainwater capture systems and find that at low volumes for single-family residences there is essentially no energy required. However, for pressurized irrigation systems or internal building uses such as flushing toilets, use of a small sump may be required. We base our energy requirements for the low savings estimate on sprinkler-based systems requiring 338 kWh/af; for the middle estimate we assume a mixture of drip- and sprinkler-system use for irrigation requiring 262 kWh/af; and for the high savings estimate we assume use of drip-based irrigation requiring 186 kWh/af.[3]

- Local variation in soil type and infiltrative capacity: As a final variable, we recognize there may be areas that we have identified as having the greatest potential savings supplied through infiltration and groundwater recharge (not including those areas designated as having a high percentage of impervious surface or as underlain by D soils) for which water harvesting may ultimately prove to be a preferred method for augmenting water supply. These may include areas underlain by shallow or contaminated groundwater. In order to demonstrate that LID is capable of achieving substantial water savings and corresponding reductions in energy use and GHG emissions regardless of what LID practice is employed, we assume, in our low savings estimate, that only 50 percent of Los Angeles County within the study area will augment water supply through infiltration, with 50 percent employing capture to augment water supply. The medium estimate assumes 75 percent infiltration and 25 percent capture, and only the high savings estimate assumes 100 percent use of LID practices that emphasize infiltration in areas overlying A, B, or C soils and containing less than 85-percent impervious surface.

APPENDIX B
GIS DATA SOURCES AND METHODOLOGY

GIS Data Sources

Data Layer	Source	Type	Scale	Date	Description
Imperviousness	National Land Cover Database (NLCD) Imperviousness Layer, U.S. Geological Survey	Raster	30m cell size	2001	Estimates impervious surface coverage as a percent imperviousness (0 - 100%) by 30-m cell.
Land Use - Los Angeles, Orange, Riverside, San Bernardino, Ventura Counties	Existing Land Use, Southern California Association of Governments (SCAG)	Polygon	Minimum 2-acre mapping unit	2001 and 2005	Aerial-based existing land use survey across SCAG region.
Land Use - San Diego County	Existing Land Use, San Diego Association of Governments (SANDAG)	Polygon	Unspecified	2000 and 2007	San Diego County land use information based on aerial photography, County Assessor Master Property Records file, and other ancillary information.
Land Use - Almeda, Contra Coast, Marin, Napa, Santa Clara, San Francisco, San Mateo, Solano, Sonoma Counties	Generalized Planned Land Use, Association of Bay Area Governments (ABAG)	Polygon	Unspecified	2006	Compilation of city and county general plans for the ABAG region.
Soils - Detailed (where available)	SSURGO, U.S. Department of Agriculture, Natural Resources Conservation Service	Polygon	1:24,000	2002 - 2007	Detailed soil map units and associated attribute date (hydrologic group).
Soils - General (where detailed is unavailable)	STATSGO, U.S. Department of Agriculture, Natural Resources Conservation Service	Polygon	1:250,000	1994	Generalized soil map units and associated attribute data (hydrologic soils group).
Roads	U.S. Detailed Streets, StreetMap USA, ESRI	Line	1:50,000	2000	Enhanced TIGER 2000-based streets dataset, with road type classification.

GIS PROCESSING STEPS

Soils Data Processing:

1. Combine all SSURGO datasets that overlay the selected land use sets (2000/01 and 2005/07), and convert the mixed hydrologic groups (A/D, B/D, C/D) to D groups. Remove NO DATA records and records without a hydrologic group. Dissolve by hydrologic group.
2. Isolate STATSGO datasets that overlay the selected land use sets (2000/01 and 2005/07). Set a relate between the STATSGO map units and the STATSGO component table, and select all component records that correspond to the isolated STATSGO units.
3. In the subset STATSGO component table, create a concatenated field of the MUID and the HYDGRP. Sum the COMPPCT (component percents) by this concatenated field to get a total percent in each hydrologic group by map unit.
4. Create a new summary table from the summed STATSGO component percent table by selecting the maximum component percent for each map unit. This will be the "dominant" hydrologic group for that map unit. Verify these maximums, and if the maximum percent was assigned a null hydrologic group (e.g., URBAN LANDS), then take the next highest percentage hydrologic group.
5. Join the cleaned and verified maximum hydrologic group table to the STATSGO layer and dissolve by hydrologic group.
6. Create a copy of the SSURGO dataset and merge all polygons into a smaller set of units (all together or, if that gives errors, in a few sections). Erase this layer from the STATSGO layer.
7. Merge the original SSURGO layer with the erased STATSGO layer to create a single combined soils layer.

Road Buffer Delineation:

1. Add buffer distance attribute to streets layer based on type. For road classes 0, 1, 2, and 3 assign a buffer of 48ft (96ft total width) and for classes 4, 5, 6 assign a buffer of 24ft (48ft total width). Classes 7, 8, and 9 are dropped from the analysis. NOTE FOR BAY AREA ANALYSIS: For classes 0 and 1 assign a buffer of 80ft (160ft total width) and remove completely from the land use layer to approximate a "Highways" land use class. The rest of the classes are the same as described.
2. Select roads that intersect the model (2005/07) land uses, and port to a new file.
3. Using the new roads subset, dissolve by the buffer distance field.
4. Buffer the dissolved roads layer using the buffer distance field. Do NOT opt to dissolve adjacent boundaries – this tends to cause problems when buffering the larger streets files. Repair Geometry.
5. Start editing completed buffer file, manually select all features and merge. If the number of features is very large, do this in batches. Once the feature merge is complete, explode multipart polygons – if you had to do the merge in batches, then port each batch to its own shapefile before attempting the explode multipart.
6. Union the completed road buffer sections into one file. Use this processed road buffer dataset for road surface acreage calculations.

Land Use / Soils Analysis:

1. Intersect the model land use layer with the soils layer – once using the 2000/01 data and once using the 2005/07 data. In each new dataset, add a new text field that concatenates the county name, hydrologic soils group, and the land use group. Update the area and acres fields.
2. Run zonal statistics using the land use/soils intersected layer from 2000/01 and the imperviousness grid. Make sure to set the Spatial Analyst options to use the extent of the imperviousness grid, snap to the imperviousness grid, and use a cell size of 10m. The zone is the concatenated county/soils group/land use group field.
3. Create a summary table of the land use/soils 2005/07 attribute table by the concatenated county/soils group/land use group field. Summarize the total acreage, first county, first soils group, and first land use group.
4. Intersect the land use/soils 2005/07 layer with the roads buffer layer. Repair Geometry. Update the area and acreage fields.

5 Create a summary table of the intersected land use/soils and road buffer layer by the concatenated county/soils group/land use group field. Summarize the total acreage, first county, first soils group, and first land use group.
6 Run zonal statistics using the land use/soils intersected layer from 2005/07 and the precipitation grid. Make sure to set the Spatial Analyst options to use the extent of the precipitation grid, snap to the precipitation grid, and use a cell size of 10m. The zone is the concatenated county/soils group/land use group field.

Southern California High/Low Impervious Area Delineation:

1 Set the Spatial Analyst options to the extent of the imperviousness grid, snap to the imperviousness grid, and set the cell size to 10m. Run a reclassify to classify all areas less than 85 as NoData and all areas greater than or equal to 85 as 85.
2 Convert the reclassified grid to a polygon coverage. Add and update an acreage field, and delete all polygons less than 10 acres.
3 Union the high imperviousness polygons with the already intersected land use/soils layer, once for each year.
4 Select all polygons from the unioned layer that have a grid value of 85 and a land use value of greater than 0 (or non-null) – these are the new high impervious areas.
5 Select all polygons from the unioned layer that have a grid value of 0 and a land use code value of greater than 0 (or non-null) – these are the new low impervious areas.
6 Run steps 2-6 of the land use / soils analysis using the high and low imperviousness layers.

Bay Area High/Mid/Low Impervious Area Delineation:

7 Set the Spatial Analyst options to the extent of the imperviousness grid, snap to the imperviousness grid, and set the cell size to 10m. Run a reclassify to classify all cells less than or equal to 20 as 20, between 20 and 85 as NoData, and greater than or equal to 85 as 85.
8 Convert the reclassified grid to a polygon coverage. Add and update an acreage field, and delete all polygons with (a) a value of 20 and size less than 5 acres, or (b) a value of 85 and a size less than 10 acres.
9 Union the high/low imperviousness polygons with the already intersected land use/soils layer.
10 Select all polygons from the unioned layer that have a grid value of 85 and a land use value of greater than 0 (or non-null). Export to new layer – these are the new high impervious areas.
11 Select all polygons from the unioned layer that have a grid value of 20 and a residential land use class. Export to new layer – these are the new low impervious areas.
12 Select all polygons from the unioned layer that have a non-null land use value and have not already been classified as either low or high impervious. Export to new layer – these are the new mid impervious areas.
13 Run steps 2-6 of the land use / soils analysis using the low, mid, and high imperviousness layers.

APPENDIX C - Sample Calculations for Riverside County

Runoff Calculations for A,B, and C Soils

	Low Rise Apartments	Strip Development	Total	Calculation
Percent impervious surface	49.37	52.71		Taken from land use data
Percent impervious surface (w/o roads)	41	42		
Acres Development (dev.), 2007	2,856.47	3,885.34		Taken from land use data
Est. impervious acres 2007	1,410.10	2,047.99		Acres dev. 2007 × percent impervious surface
Road acres 2007	406.25	742.41		
Impervious acres w/o roads 2007	1,003.86	1,305.58		Est. impervious acres 2007 – Road acres 2007
Avg. annual precipitation (feet)	0.974	1.024		
Annual precipitation (for whole property) (af)	2385.90	3219.35		Avg. annual precipitation × (Acres dev. 2007 – Road acres 2007)
Post-dev. impervious runoff (af)	928.63	1270.46	2199.09	Avg. annual precipitation × Impervious acres w/o roads 2007 × runoff coefficient (0.95)
Dry weather runoff (af)	320.61	407.28	727.89	Runoff volume per acre of pervious surface per minute (0.152 gallons) × Total Pervious Acres (Calculated by: (Acres dev. 2007 – Est. impervious acres 2007) × minutes per day (1440) × days without precipitation (335 in Riverside County) / gallons per acre-foot (325851 gallons)
Est. annual acres of dev.	87.23	43.06	130.29	(Acres dev. 2007 – Road acres 2007) × Annual dev. rate for Riverside County (Residential (3.56%); Commercial (1.37%))

	Low Rise Apartments.	Strip Development	Total	Calculation
Est. acres new dev. 2030	1919.01	947.28	2866.29	Est. annual acres of dev. × 22 years
Est. acres new dev. impervious surface 2030	786.22	393.50	1179.72	Est. acres new dev. 2030 × Percent impervious surface (w/o roads)
New post-dev. impervious surface runoff 2030 (af)	727.30	382.92	1110.22	Est. acres new redev. impervious surface 2030 × Avg. annual precipitation × runoff coefficient (0.95)
Est. annual acres redevelopment (redev.)	15.44	43.06	58.49	(Acres dev. 2007 – Road acres 2007) × Redevelopment rate for Riverside County (Residential (0.63%); Commercial (1.37%))
Est. acres redev. 2030	339.60	947.28	1286.88	Est. annual acres redev. × 22 years
Est. acres new redev. impervious surface 2030	139.13	393.50	532.63	Est. acres redev. 2030 × Percent impervious surface (w/o roads)
New post-redev. surface runoff 2030 (af)	128.71	382.92	511.62	Est. acres new redev. impervious surface 2030 × Avg. annual precipitation × runoff coefficient (0.95)
New dry weather runoff 2030 (af)	295.54	245.51	541.05	Runoff volume per acre of pervious surface per minute (0.152 gallons) × Total Pervious Acres from New Development and Redevelopment (Calculated by: ((Est. acres new dev. 2030 – Est. acres new redev. impervious surface 2030) + (Est. acres redev. 2030 – Est. acres new impervious redev. surface 2030)) x minutes per day (1440) × days without precipitation (335 in Riverside County) / gallons per acre-foot (325851 gallons)
Runoff from new roads 2030 (af)	294.33	217.74	512.07	Avg. annual precipitation × Road acres 2007 × Development Rate (Residential (3.56%); Commercial (1.37%)) × 22 years
Runoff from resurfaced roads 2030 (af)	113.27	217.74	331.01	Avg. annual precipitation × Road acres 2007 × Development Rate (1.37%) × 22 years

Water Calculations

	Total	Calculation
Post-dev. impervious runoff (af)	2199.09	
Dry weather runoff (af)	727.89	
A, B, C soil total runoff (w/o Roads) 2008 (af)	2926.98	Post-dev. impervious runoff + Dry weather runoff
New and redevelopment runoff 2030 (af)	1621.84	New post-dev. impervious surface runoff 2030 + New post-redev. surface runoff 2030
New dry weather runoff 2030 (af)	541.05	
Runoff from new roads 2030 (af)	512.07	
Runoff from resurfaced roads 2030 (af)	331.01	
Retrofit runoff 2030 (af) (equal to redevelopment)	255.81	New post-redev. surface runoff 2030
2030 ABC SOIL LOW TOTAL WATER SAVINGS (AF)	1782.78	30% evapotranspiration loss; 50% of new roads developed as green streets; retrofits incorporate LID at 25% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 × 0.5) + (Retrofit runoff 2030 × 0.25)) × 0.7 (evapotranspiration)
2030 ABC SOIL MED TOTAL WATER SAVINGS (AF)	2267.44	20% evapotranspiration loss; 65% of new roads developed as green streets; 25% of resurfaced roads developed as green streets; retrofit incorporate LID at 50% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 x 0.65) + (Runoff from resurfaced roads 2030 x 0.25) + Retrofit runoff 2030 x 0.5) × 0.8 (evapotranspiration)
2030 ABC SOIL HIGH TOTAL WATER SAVINGS (AF)	2694.48	10% evapotranspiration loss; 80% of new roads developed as green streets; 50% of resurfaced roads developed as green streets; retrofit incorporate LID at 50% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 x 0.65) + (Runoff from resurfaced roads 2030 x 0.25) + Retrofit runoff 2030 x 0.5) × 0.9 (evapotranspiration)

Energy Calculations

	Total (MWh)	Calculation
2030 ABC SOIL LOW TOTAL ENERGY	4075.44	(2030 ABC SOIL LOW TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL LOW TOTAL WATER SAVINGS × Groundwater energy requirement Inland Empire Utilities District (0.95 MWh/af))
2030 ABC SOIL MED TOTAL ENERGY	6022.33	(2030 ABC SOIL MED TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL MED TOTAL WATER SAVINGS × Groundwater energy requirement Los Angeles County (0.58 MWh/af))
2030 ABC SOIL HIGH TOTAL ENERGY	7776.27	(2030 ABC SOIL HIGH TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL HIGH TOTAL WATER SAVINGS × Groundwater energy requirement West Basin (0.35 MWh/af))

Variables for calculations (all figures in MWh/af):
Groundwater energy requirement: West Basin: 0.35
Groundwater energy requirement: LA County : 0.58
Groundwater energy requirement: Inland Empire Utilities Agency: 0.95
Capture pump energy – Drip: 0.186
Capture pump energy – Mix: 0.262
Capture pump energy – Sprinkler: 0.338
West Branch SWP: 2.58
East Branch SWP: 3.236
Carlsbad desalination: 4.6
San Francisco Bay area desalination: 4.4

To calculate estimated CO_2 reductions for each estimate, multiply the energy savings total (MWh) by 0.437 to determine metric tons CO_2 equivalent.

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14 Irvine Ranch Water District, July 2004, The Residential Runoff Reduction Study, http://www.irwd.com/Conservation/R3-Study-Revised11-5-04.pdf.

15 Natural Resources Conservation Service, 2009, Web Soil Survey: Glossary, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx; Horner, Richard R., 2007, Initial Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices (LID) for the San Francisco Bay Area, http://docs.nrdc.org/water/wat_09081001.asp.

16 See City of Los Angeles, Watershed Protection Division, City of Los Angeles Standard Urban Stormwater Mitigation Plan Infiltration Requirements & Guidelines, http://www.lastormwater.org/siteorg/download/pdfs/tech_docs/SUSMP_Infiltration_Req.pdf. The City of Los Angeles generally does not require infiltration at sites with groundwater within 10 feet of existing grade.

17 California Department of Water Resources, October 2003, California's Groundwater – Bulletin 118 Update 2003, http://www.groundwater.water.ca.gov/bulletin 118/.

18 Southern California Area Governments, 2008, Integrated Growth Forecast, http://www.scag.ca.gov/forecast/index.htm.

19 San Diego Association of Governments, Demographics, http://www.sandag.cog.ca.us/index.asp?classid=26&fuseaction=home.classhome.

20 See Association of Bay Area Governments, 2007, Projections 2007: Regional Projections, http://www.abag.ca.gov/planning/currentfcst/regional.html.

21 California Department of Finance, July 2007, Population Projections for California and Its Counties 2000-2050, http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Projections/P1/P1.php.

22 See Nelson, Arthur C., 2004, Toward a New Metropolis: The Opportunity to Rebuild America, Brookings Institution, http://www.brookings.edu/reports/2004/12metropolitanpolicy_nelson.aspxerica.pdf.

23 Ibid.

24 Ibid.

25 California Air Resources Board, December 2008. *Climate Change Scoping Plan, Appendix I.* http://www.arb.ca.gov/cc/scopingplan/document/scopingplandocument.htm

26 Where data, or a range of data were available for each variable, those sources are presented in Appendix A. Where data were not available, we present a discussion on how we created estimates for the individual variables, and provide a basis for our methodology.

27 See Appendix A; Los Angeles and San Gabriel Rivers Watershed Council, 2008, Water Augmentation Study, http://www.lasgrwc.org/WAS.htm.

28 Horner, Richard R., 2007, Supplementary Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices (LID) for the San Francisco Bay Area, http://docs.nrdc.org/water/wat_09081001.asp

29 Nelson, Arthur C., 2004, Toward a New Metropolis: The Opportunity to Rebuild America, Brookings Institution, http://www.brookings.edu/reports/2004/12metropolitanpolicy_nelson.aspx

30 See Appendix A. Derived from figures provided by Jack Schulz, American Rainwater Catchment Systems Association, personal communication, March 17, 2009.

APPENDIX A

1 Horner, Richard R., 2007, Supplementary Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices (LID) for the San Francisco Bay Area, http://docs.nrdc.org/water/wat_09081001.asp

2 Cohen, Ronnie, Nelson, Barry, Wolff, Gary, August 2004, Energy Down the Drain: The Hidden Costs of California's Water Supply, Natural Resources Defense Council, http://www.nrdc.org/water/conservation/edrain/contents.asp.

3 Jack Schulz, American Rainwater Catchment Systems Association, personal communication, March 17, 2009. These figures are based upon: residential irrigation systems using a 1/3 to 1/2 horsepower pump operating at up to 5 gallons per minute, pressurized to 15 psi for drip irrigation or 30 psi for sprinkler irrigation, and drawing from a 100-500 gallon aboveground storage tank; and commercial irrigation systems using a 4-5 horsepower operating at up to 160 gallon per minute, pressurized to 9 psi for drip irrigation or 40 psi for sprinkler irrigation, and drawing from a 20,000 gallon tank. Pump efficiency in residential systems is assumed to be 48 percent, and to be 75 percent in commercial systems. See also Grady, Caitlin, and Younos, Tamim, September 2008, Analysis of Water and Energy Conservation of Rainwater Capture System on a Single Family Home, Virginia Water Resources Research Center Special Report No. SR39-2008.