Prepared for The Trust for Public Land
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ICF International

Quantifying the Greenhouse Gas Benefits of Urban Parks

THE TRUST *for* PUBLIC LAND
CONSERVING LAND FOR PEOPLE

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CONSERVING LAND FOR PEOPLE

White Paper

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Executive Summary

With governments at all levels looking at ways to reduce greenhouse gas (GHG) emissions, increasing attention is being paid to the relationship between land use patterns and GHG emissions. Parkland and recreational space is an important element of land use planning that deserves consideration for its potential to reduce net GHG emissions. Urban green space serves diverse purposes, ranging from neighborhood and city parks to river parkways, bike paths, and street trees, which in turn can produce different types of GHG benefits.

The goal of this paper is to help inform local planning decisions by discussing the potential GHG benefits of adding green space to an urban area and introducing methodologies for estimating potential GHG reductions. We are not attempting to provide GHG inventory or accounting methodologies, as those methodologies are already well-established and address a broader range of GHG sources and sinks. Instead, this is an illustration of the types of GHG benefits that warrant further exploration when designing an urban park or when making larger policy decisions about land use. For example, here we provide several of the types of calculations that could be used when determining quantitative benefits to GHG emissions. We look at potential groundwater recharge, reduction of vehicle trips, promotion of bicycling and walking, mitigation of the urban heat island effect, and the carbon sequestration expected from the addition of trees. When determining the benefits in practice, it will be necessary to have detailed knowledge about that particular location: soil type, ground cover, carbon sinks and sources within the boundaries of the park, expected irrigation requirements, energy use to maintain the park, vehicle miles produced or reduced as a result of the park, plant types, spatial extent of the park, water imports for the particular district, and municipal water district policy, among other information.

The transportation sector is one of the largest sources of GHG emissions, representing 41 percent of GHG emissions in California (California Energy Commission, 2006a). One important way that cities and regions can reduce the amount of transportation-related GHGs is by locating municipal services in areas accessible by walking, biking, and public transit. Public parks provide the most common leisure opportunities for local residents and enjoy widespread popularity. Cities that take care to locate, design, and maintain urban parks in accessible locations can address the needs of their citizens for open space, while providing an attractive local amenity that can be accessed by walking or biking.

The expansion of green spaces in urban areas has been identified as a pathway for reducing the energy use and CO_2 emissions associated with water delivery by providing a medium for wastewater recycling and increased stormwater retention (Anderson, 2003; Kramer and Dorfman, 2000). The delivery and treatment of water require a significant amount of energy. Pumping and delivery of water accounted for approximately eight percent of California's total electricity use in 2004. The water-related energy use is not evenly distributed throughout the state, however. In water districts that import much of their water supply from elsewhere in the state or from out of state, the energy use associated with obtaining water is much greater than for areas that are able to get water from local groundwater aquifers.

The most direct and quantifiable impact on water resources is through the increase in groundwater recharge that is associated with the high permeability of green spaces, compared with the low permeability surfaces of densely developed

areas. The benefit to water resources is dependent on the spatial area and the "type" of green space. If the primary purposes of adding green space are to aid in water conservation, mitigation of the urban heat island effect, and the reduction of greenhouse gases, a larger fraction of the ground cover should be highly permeable surfaces. More hydrologically-beneficial urban green spaces include community gardens, stormwater ponds/wetland buffers, and neighborhood parks. Some municipalities have also added subsurface equipment to first separate sediment, pollutants, and trash from stormwater, and subsequently store the water in large chambers, which gradually release the water into the soil to prevent the oversaturation of soils, thus minimizing runoff and maximizing aquifer recharge. For even more efficient collection and retention of water for groundwater recharge, green space could be planned in areas that naturally receive runoff from surrounding land, such as in a basin; at the base of a hill; or adjacent to a river.

Through the planting of trees, urban green space also provides the opportunity to not only sequester substantial quantities of carbon pulled from the air and soil, but also reduce local energy consumption by providing cooler surfaces and additional shade for buildings. As trees grow, they remove carbon dioxide from the atmosphere and store it in the form of biomass carbon in the leaves, roots, branches, and trunk. A young sapling can sequester anywhere from 1.0 to 1.3 lbs. carbon each year, while a 50 year old tree can sequester over 100 lbs. annually (DOE 1998). With the sequestration of many trees put together, urban trees can be a significant sink for carbon dioxide. The rate of net sequestration per area of tree cover can be as high as 0.29 kg C/sq. m tree cover (EPA 2008). Indeed, the sequestration by urban trees in the city of New York is estimated to be 38,374 MT annually, and other cities can also claim similar GHG benefits. In total, urban trees in the US sequestered an estimated 95.5 MMTCO2 in 2006 (EPA 2008).

The trees and vegetation provided by urban parks also provide an effective way to reduce urban heat islands. On an individual level, carefully selected and planted trees can reduce the energy consumption for individual buildings. Trees achieve this effect by providing shade and evapotranspiration to cool buildings during summer, thereby reducing the need to run air conditioners and consume electricity (EPA, 2007). Researchers have demonstrated that trees and other heat island reduction measures can combine to reduce building carbon emissions by 5-20 percent (Akbari and Konopacki, 2003).

The air quality, water quality, recreational, and other social benefits parks provide have long been known, but as governments develop a comprehensive response to climate change, increasing attention will be paid to the role parks play in reducing GHG emissions. The methods outlined here—particularly in the areas of transportation and groundwater recharge—can be used in conjunction with existing carbon sequestration estimators and heat island reduction calculators to develop a broader picture of the reductions that can be realized by increasing the availability and distribution of urban parks. Although these methodologies do present some uncertainty, knowledge of parks' GHG benefits provides planners with yet another powerful argument for increasing public and private investment in parks. With the successful introduction of more urban parks, communities can improve the quality of life for their residents while taking concrete steps toward reducing their GHG emissions.

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1 Introduction

With governments at all levels looking at ways to reduce greenhouse gas (GHG) emissions, increasing attention is being paid to the relationship between land use patterns and GHG emissions. Urban green space is an important element of land use planning that deserves consideration for its potential to reduce net GHG emissions. Urban green space serves diverse purposes, ranging from neighborhood and city parks to river parkways, bike paths, and street trees, which in turn can produce different types of GHG benefits. The goal of this paper is to help inform local planning decisions by discussing the potential GHG benefits of adding green space to an urban area and introducing methodologies for estimating potential GHG reductions.

In general, this paper does not attempt to consider the GHG impacts of a park versus a competing land use. Such a comparison would require the analysis of a broad range of GHG sources and sinks, an accounting exercise that is beyond the scope of this paper. Such GHG inventory or accounting methodologies are already well-established and do not need to be reconsidered here. Instead, this is an illustration of the types of GHG benefits that warrant further exploration when designing an urban park or when making larger policy decisions about land use. For example, here we provide several types of calculations that could be used when determining quantitative benefits to GHG emissions. We look at potential groundwater recharge, reduction of vehicle trips, promotion of bicycling and walking, mitigation of the urban heat island effect, and the carbon sequestration expected from the addition of trees. When determining the benefits in practice, it will be necessary to have detailed knowledge about that particular location: soil type, ground cover, carbon sinks and sources within the boundaries of the park, expected irrigation requirements, energy use to maintain the park, vehicle miles produced or reduced as a result of the park, plant types, spatial extent of the park, water imports for the particular district, and municipal water district policy, among other information. The range of GHG benefits explored in this paper are summarized in Table 1 below.

Table 1: Greenhouse Gas Reductions with Urban Green Space

Category	Benefit	Park Types
Transportation	Induced non-motorized transportation	Bike Paths, River Parkways, Rail Trails
	Pedestrian-accessible urban parks	Neighborhood Parks, River Parkways, City Parks
Water Resources	Increase permeable surface area, allowing groundwater recharge	River Parkways, Neighborhood Parks, City Parks, Stormwater Ponds, Community Gardens
	Stormwater collection	
Trees and Vegetation	Carbon sequestration	Neighborhood Parks, City Parks, River Parkways, Wetlands, Urban Forests, Business Parks, School Campuses
	Reduced energy consumption due to mitigation of heat island effects	

1.1 Greenhouse Gas Emissions

Scientific consensus now exists that anthropogenic greenhouse gas (GHG) emissions are contributing to global climate change (IPCC, 2007). As a growing political consensus emerges to respond to the challenges posed by climate change, policy discussions have moved toward the goal of reducing GHG emissions to 60 to 80 percent below 1990 levels by 2050 (Ewing, et al., 2008). With no clear path toward meeting this goal, governments on all levels will need to encourage a wide variety of GHG reduction strategies.

To date, most of the discussion on reducing GHG emissions has focused on energy consumption, since more than 80 percent of the United States' GHG emissions are due to the combustion of fossil fuels (EPA, 2008). The U.S. Environmental Protection Agency (EPA), for example, oversees voluntary and incentive-based programs that focus on energy efficiency, technological advancement and cleaner fuels. While cleaner fuels and more efficient energy consumption are an essential part of any long-term strategy, increasing attention is being focused on how land use decisions affect energy consumption patterns.

1.2 Smart Growth and Green Space

A growing body of evidence shows that "Smart Growth"-style neighborhood developments, featuring a compact development form and a mix of land uses, can result in lower average GHG emissions due largely to the reduced need for automobile travel, and that denser communities have lower per capita emissions than sparsely-populated rural and exurban areas (Ewing, et al., 2008). A study comparing two suburban, automobile oriented towns in the Nashville area found residents in the town with a higher average land-use density and greater transportation accessibility emitted about 25 percent less carbon dioxide per capita in addition to consuming 13 percent less water per capita (Allen and Benfield, 2003). Likewise, residents in Metro Square in Sacramento, CA live in a community with compact lots situated around common green space and emit less carbon dioxide per capita by driving half the miles of residents living in similar Sacramento developments with more sprawl (NRDC, 2000).

Public parks are a key feature of dense, mixed-use communities, providing recreational and educational opportunities, promoting community revitalization, and impacting economic development. Clearly, urban parks are an attractive amenity, which can improve the economic value and desirability of living in dense areas. Indeed, parks' value to neighborhood quality is confirmed by studies that find a statistically significant link between property values and proximity to green space, including neighborhood parks and urban forested areas. The link between property values and green spaces has been recognized dating back to, at least, the 1970s. One case study found that the value of properties near Pennypack Park in Philadelphia increased from about $1,000 per acre at 2,500 feet from the park to $11,500 per acre at 40 feet from the park (Hammer, Coughlin, and Horn, 1974). Another found that the price of residential property—based on data from three neighborhoods in Boulder, Colorado— decreased by $4.20 for every foot farther away from the greenbelt (Correll, Lillydahl, and Singell, 1978). Data from a 2000 study in Portland, Oregon indicate that the correlation between property value and proximity to green space is significant. At distances between about 100 feet from the perimeter of the park to about 1,500 feet, the price premium for homes ranged between 1.51 percent and 4.09 percent. According to a 2001 study, with homes within 1,500 feet of a natural, largely undeveloped space, the sale

prices are estimated at 16.1 percent more than for homes farther than 1,500 feet away from the space. Additional parks that are positively correlated with housing prices are golf courses and urban parks (Dunse, et al., 2007).

Urban areas that are no longer in use and may be suffering from long periods of neglect include riverfronts that were populated by once-booming industry. Many cities are facing not only the aesthetic problems posed by abandoned waterfront properties, but are also confronted with the environmental problems that can come with continuing to allow former industrial zones to sit unused. Riverfront areas are now becoming popular choices of location for urban green space planning. Revitalization of riverfronts with urban parks can: 1.) provide residents with the opportunity to engage in healthful outdoor activity, such as via a riverside bicycle or walking path; 2.) facilitate a meaningful connection between residents and the natural environment, encouraging appreciation for water resources and wildlife; 3.) inspire economic development in the area; and 4.) reduce the need for automobile trips.

The American River Parkway in Sacramento, California is a 30 mile linear park that was initially established in the early 1960s but had fallen into a state of disrepair due to lack of maintenance funding by the early 1990s. The threats to not only the facilities, such as the bike path, but to the natural habitat in the park, continued until 2004. Since the park's well-being has been prioritized, it has brought numerous benefits to the community, including a bike trail that has been ranked as one of the best in the US, a rowing facility, local economic activity that is estimated to generate approximately $260 million annually, and a salmon fish hatchery. The park has a million more visitors annually than does Yosemite National Park (ARPPS, 2008).

By providing valuable green space and recreational amenities, such parks are critical to the quality of life in dense communities. In this way, parks can facilitate a reduction in GHG emissions by alleviating some of the drawbacks of dense development (reduced private green and recreational space, increased air pollution, decreased water quality, etc.), thereby allowing more people to comfortably live in dense, mixed-use communities. On a society-wide scale, these benefits can be enormous (Ewing, et al., 2008), but the indirect relationship between parks and denser communities is difficult to estimate. With somewhat greater reliability, however, we can estimate the GHG reductions created by parks themselves.

There are numerous ways in which parks can help directly or indirectly reduce emissions: by reducing automobile trips, increasing groundwater recharge, reducing the "heat island" effect associated with paved surfaces, and utilizing trees to sequester carbon and reduce energy consumption for cooling. Large linear parks such as rail trails, bike paths, or river parkways that form part of the transportation infrastructure can reduce automobile use by enabling people to replace automobile trips with bicycle or pedestrian trips. Since parks are trip destinations themselves, a wider distribution of parks in an urban area will increase the population that is within walking distance to parks, thereby reducing automobile trips. Meanwhile, by providing a large permeable surface, parks can foster groundwater recharge from storm events. In areas dependent on distant sources of drinking water, this feature can reduce the significant energy demands associated with the long-distance conveyance of water. Last but not least, trees reduce net GHG emissions by removing CO_2 from the atmosphere and storing it for the life of the tree. When positioned near buildings, shade trees can reduce the need for forced cooling, thereby reducing energy consumption. While there are likely

numerous other GHG benefits, these are among the most understood and direct.

Given both the quality of life benefits of urban parks and the GHG benefits, planners and developers should begin to think of urban parks as GHG mitigation measures, part of any comprehensive plan to respond to the challenges posed by climate change. In order to effectively be considered as proper mitigation measures, one must be able to estimate the GHG benefits of an urban park with reasonable confidence. In this paper, we seek to explore ways of estimating these benefits for areas where methods are not currently available (automobile trip reduction and groundwater recharge), and review those areas where methodologies are widely available (carbon sequestration and energy benefits of trees). Such methodologies may provide the framework for the future development of an online tool to help planners and developers estimate the GHG benefits of increasing parks in their communities. Although green strategies discussed here can be implemented for communities of all ages, the most cost-effective route for developing sustainable communities and green space is to include it in the initial design. For example, if a community would like to reuse gray water from residences and businesses for public irrigation or for recycling back into the groundwater aquifer, it would be more efficient to build the necessary physical infrastructure, such as pipelines, storage, or aquifer injection systems, into the initial development.

2 Reducing GHG Emissions From Transportation

Greenhouse gas emissions from mobile sources such as cars, trucks, and buses constitute a major source of the air pollutants that are linked to climate change. The EPA estimates that, in the United States, GHG emissions from the transportation sector accounted for approximately 28 percent of global warming potential (GWP)-weighted emissions in 2006, growing from 25 percent of total GWP-weighted emissions in 1990. Emissions from this source category grew by 27.6 percent over this time, from 1,544 million metric tons of carbon dioxide equivalent (MMTCO2E) to 1,970 MMTCO2E, and comprised much of the increase in total national emissions during this period, second only to the emissions related to electricity generation (U.S. EPA, 2008). In California, where the most recent inventory data are from 2004, 41 percent of all GHG emissions are generated by the transportation sector, making it the largest contributor of GHGs in the state (California Energy Commission, 2006a).

The U.S. government, along with State and local partners, has implemented strategies and executed public programs to reduce GHG emission from transportation sources. Some of the most prominent projects are those funded through the Congestion Mitigation and Air Quality (CMAQ) Improvement Program, which does not have the explicit goal of working to reduce GHG emissions, but acknowledges the reductions as an ancillary benefit of its air quality objectives. The CMAQ Improvement Program provides funding to States and metropolitan planning organizations (MPOs) for projects that reduce transportation-related emissions of air pollutants; it also funds the regional level transportation demand management (TDM) programs, which coordinate city-wide marketing efforts to support transit use, ridesharing, and other non-motorized travel options.

One important way that cities and regions can reduce the amount of transportation-related GHGs is by locating municipal services in areas accessible by walking, biking, and public transit. Public parks provide the most common leisure opportunities for local residents and enjoy wide-

spread popularity. In Fairfax County, Virginia, for example, public parks had been visited by at least 70 percent of households in every major racial/ethnic group in the County (Fairfax County Needs Assessment, 2004). Cities that take care to locate, design, and maintain urban parks in accessible locations can address the needs of their citizens for open space, while providing an attractive local amenity that can be accessed by walking or biking.

The built environment has a powerful role to play in our transportation decision-making, and urban parks can serve to mitigate some GHG emissions from transportation sources. Parks can provide an attractive travel environment for non-motorized transportation modes between other origins and destinations, such as home and office. Additionally, by providing a safe location, separate from cars, parks can actually increase the amount of travel by walking and biking, and play a role in reducing auto trips (Bay Area Air Quality Management District, 2006; Lindsey, Wilson, Rubchinskaya, Yang, and Han, 2007). Urban parks can also reduce transportation-related GHGs by serving as pedestrian-accessible destinations for recreational activities. When located in urban areas that are easily accessible by walking or biking, small parks can obviate the need for automobile trips to other parts of the city or large regional parks to satisfy everyday recreation needs.

Finally, for those who do not have a means of private transportation, pedestrian-accessible urban parks may provide the primary opportunity to experience open space. As the equitable access to nature is an environmental justice issue, this is an important ancillary benefit to urban parks. In the future, small parks can play a vital role in making cities more sustainable. They can provide benefits for air quality, wildlife habitat, and watershed health, while enhancing neighborhood livability. As cities strive to increase densities and to reduce the consumption of land on the urban edge, small parks will become increasingly important parts of the green infrastructure of the city and the metropolitan region.

2.1 Induced Non-Motorized Travel

Trips accomplished by walking, biking, or other modes that do not generate GHG emissions can be encouraged through the establishment, design, and maintenance of urban parks. Just as the creation of an extensive road network and the expansion of road capacity results in increased automobile travel, the creation of more extensive bicycle and pedestrian infrastructure will lead to increased walking and biking; this principle is known as induced travel demand and is a well-researched concept (Noland, Lewinson, 2000). Similarly, urban parks that provide a safe, direct way to make non-motorized trips may provide enough incentive to induce some people to shift modes (Nelson and Allen, 1997).

To serve as an effective facility to induce non-motorized travel and reduce automobile travel, the form and functionality of the urban park is important. The most common and successful type of park for creating opportunities for non-motorized travel are greenways, rail trails, and bike paths. Often designed as a route for workday commuters, these urban parks are usually long and narrow with one or more paved walkways. When designed as networks of linear corridors of parkland that connect recreational, natural, and/or cultural resources, these parks provide regionally significant links to comprehensive regional greenways and open space. Thoughtfully located small parks that are highly accessible to residents and connected to the larger open-space network will also achieve high levels of induced non-motorized travel. Riverfronts are a good multi-purpose option when looking to create

a park that is long and linear. Abandoned industrial areas along rivers in urban areas could be modified to provide not only an aesthetically pleasing river parkway, but can act to provide transportation alternatives through pedestrian and/or bicycling paths.

Smaller parks that serve neighborhoods, employment and mixed use centers offer a variety of active and/or passive recreation opportunities. As these local parks are often located for ease of non-motorized access from surrounding areas, they are typically less than five acres and often under one-half acre. These small parks can induce non-motorized travel demand by providing a pedestrian linkage between two neighborhoods or linking a residential and a shopping area. In this way, small local parks can provide the necessary infrastructure to ensure safe passage for a person traveling by non-motorized means to feel comfortable.

2.1.1 Non-Motorized Urban Park Use

Latent demand for non-motorized travel likely exists most acutely in urban areas where a quarter of all trips are less than one mile in length, an acceptable distance for walking or bicycling (NGA, 2000). To date however, little research has been done to quantify the increases in the number of people choosing non-motorized transportation after the implementation of an urban park. Planners and city officials need the results of these data and modeling exercises for estimating the non-motorized traffic on urban trails, and consequently the transportation GHG mitigation benefit. A few of these studies are summarized below.

Urban parks can act to provide segues between a start or end point of a trip and public transportation. So, not only is the park contributing to a decrease in automobile usage, but can also act to foster use of mass transit. Stamford, CT is attempting to revitalize its riverfront through the addition of a "world class" urban park. One of Stamford's goals for the Mill River Collaborative is to encourage the use of public transportation by linking commuter rail stations and office buildings with green space, which is not only safer than walking or biking along urban streets, but will also provide an attractive travel environment (Mill River Collaborative, 2008).

Most information about trail use has been based on samples of trail traffic over short periods of time (Lindsey, 1999; Lindsey and Nguyen, 2004) or counts of surrogate measures such as cars in parking lots (PFK Consulting, 1994). Researchers have shown that traffic on pedestrian and cycling facilities and routes varies greatly by location, season, day of week, time of day, and weather. These factors contribute to the uncertainty associated with quantifying the amount of average daily users attributable to a park and the number of vehicle trips avoided.

A study of a network of 30 infrared monitors on 33 miles of multiuse greenway trails in Indianapolis, Indiana revealed that different segments in the network have different levels of use. The trails, located mostly in north-central Indianapolis, have been constructed along rivers or creeks, a canal, and an historic rail corridor, and they connect a wide variety of land uses, including parks, residential, commercial, and industrial. Annual traffic ranges from approximately 22,000 on one segment to more than 600,000 on a segment of the longest trail in the city. The median annual traffic across all monitoring locations was nearly 102,000. Over the 12-month period, mean monthly traffic across the 30 locations ranges from approximately 1,800 to nearly 51,000 (Lindsey, 2007).

Portland, Oregon undertook a significant expansion of its bicycle facility network (both on- and off-road) between 1990 and 1999. As the city's investment in these facilities grew, so did the trails'

use by pedestrians and bicyclists. Table 2 below shows this increase in non-motorized transportation use during the ten-year facility investment period. The city tracked usage rates by counting the number of bicyclists at the three major bridge crossings into the downtown core. While this captures a significant portion of the usage, some new non-motorized trips will also be accomplished outside the central city; these were not taken into account. During this time, the city's population increased by 14 percent and auto use only by 8 percent.

Table 2: Bicycle Facility Investment and Use in Portland, Oregon

	1990	1995	1999
Network Miles	50	120	200
Funding (cumulative)	$1 million	$3 million	$6 million
Bridge crossings	1,500	3,000	5,500

Source: Trails & Greenways: Advancing the Smart Growth Agenda. 2002.

Finally, surveys conducted at an urban park in north-central Pennsylvania, the Pine Creek Rail Trail, reveal additional attitudes. The 62.6-mile trail is a former railroad that has been converted into a nature path. Surveys of users along the trail in 2006 showed the majority of trail user survey respondents reside in Pennsylvania (86.0 percent), and the trail attracts users from New York (5.4 percent), Maryland (1.7 percent), New Jersey (1.0 percent) and 20 other states (5.6 percent). As a 'destination trail,' 41.6 percent of users reported they used the trail a few times during the year. Nearly 64 percent of the respondents indicated biking as their primary activity. A trip to the trail for most users involves the investment of more than an hour of walking or biking. More than 62 percent of the users spend at least two hours on the trail during an outing.

2.1.2 Methods for Calculating Transportation GHG Mitigation

The GHG reductions associated with induced non-motorized travel demand on a bike trail or other similar park can be estimated using the following simple equation;

$E_R = A * L * EF$

Where:

E_R = GHG emissions reduced

A = Motor vehicle trips reduced

L = Average length of bike/pedestrian trips

EF = Motor vehicle CO_2 emissions factor

Estimating the number of motor vehicle trips reduced requires knowing the total number of users and the percentage of users who are using the facility to replace a vehicle trip. Clearly, the usage is highly variable by time of day, weather, and season, while city and regional preferences will also strongly influence usage patterns. Meanwhile, the mode shift from motor vehicle to rail will depend on the facility's location relative to other land uses in the area. Due to the highly variable nature of these factors, there is no substitute for field observation and surveys of usage patterns.

If the facility already exists, use can be estimated by taking traffic counts, and if the facility is being planned or use data are not available, usage can be estimated by multiplying the population of the area surrounding the path by the anticipated use rate. For example, if 1,000 people live within ¼ mile of the path and it is anticipated that the average resident will use the path ten times per year, then the estimated number of annual trips is 1,000 x 10 = 10,000. In this case, estimates should be validated after the path is completed.

The usage should then be adjusted to reflect only those trips that offset a motor vehicle trip. The number of motor vehicle trips reduced can be

estimated in various ways, including use of bicycle/pedestrian factors associated with different types of surrounding land uses, studies of similar bicycle projects, or modeling. One method, developed by the California Air Resources Board, calculates auto trips reduced as a function of average daily traffic (ADT) on a roadway parallel to a bicycle path, though this methodology is most appropriate when the pathway connects two destination areas.

> Auto trips reduced = (ADT) x (Adjustment on ADT for auto trips replaced by bike trips) x (operating days)

The CO_2 emissions factor (EF) can be produced using the MOBILE model, online emissions calculators, or U.S. EPA estimates.[1] Based on the U.S. EPA estimate of 2,417 grams of carbon emitted per gallon of gasoline (EPA, 2008), CO_2 emissions per mile can be estimated by multiplying carbon emissions by the ratio of the molecular weight of CO_2 (m.w. 44) to the molecular weight of carbon (m.w.12) and then dividing by the national average passenger vehicle fuel economy of 22.4 miles per gallon (USDOT, 2006). This equation is shown below: [2]

> CO_2 emissions from gasoline, per mile = (2,417 grams C/gallon of gasoline) x (44 g CO_2/12 g C) / 22.4 miles/gallon = 396 grams CO_2 / mile = 0.396 kg CO_2/mile
> ⇨The CO_2 EF, as estimated above, is 0.396 kg CO_2/mile.

This method will be illustrated in the following section.

2.1.3 A Case Study Bike Path: San Francisco, CA

This example includes development of a single 1.13 mile bike lane, and is based on a project in the San Francisco Bay Area, California, which included installation of new pavement, signage, and bike lane striping. The new bike lane provides residents bike access to education, employment, shopping, and transit. Within one-quarter mile of the project, there is a college, a shopping center, a light rail station, and an office building. The parameters of the project consist of:

- 1.13 miles of bike lanes, both sides
- 1.8 mile average bike trip in the region
- 200 operating days

Step 1: Estimate auto trips reduced. In this case, consistent with methods developed by the California Air Resources Board (CARB), auto trips reduced are calculated as a function of average daily traffic (ADT) on an appropriate roadway parallel to the bicycle project connecting two destination points, such as a shopping center and a residential area. [3]
= (ADT) x (Adjustment on ADT for auto trips replaced by bike trips) x (operating days)
= (20,000 vehicles) x (0.0109 mode change factor) x (200 days)
= 43,600 trips

Step 2: Estimate VMT reduced.
= (Auto trips reduced) x (Average length of bike trips)
= (43,600 trips) x (1.8 miles)
= 78,480 VMT

Step 3: Calculate annual emissions reduction.
= (Annual auto VMT reduced) x (Per mile

[1] The U.S. EPA's MOBILE model is an emission factor model for predicting gram per mile emissions of HC, CO, NOx, CO2, PM, and toxics from cars, trucks, and motorcycles under various atmospheric and speed conditions. The model contains emissions factor lookup tables which can be tailored to local conditions. In addition, the MOBILE model accounts for the emissions at varying travel speeds, idling emissions, and emissions from cold or hot start engine combustion.

[2] More information on the U.S. EPA calculation is available at: www.epa.gov/otaq/climate/420f05001.htm

[3] More information on the California Air Resources Board (CARB) methodology for determining the cost effectiveness of funding air quality projects at http://www.arb.ca.gov/planning/tsaq/eval/mv_fees_cost-effectiveness_methods_may05.doc. When determining the benefits of adding a bicycle path, please note that if a bicycle path or bicycle lane currently exists parallel to the roadway, the calculation is not valid.

CO_2 emission factor)
= (78,480 VMT) x 0.396 kg CO_2/mile
= 31,078 kg CO_2
= 31.1 metric tons (MT) CO_2

2.2 Pedestrian-Accessible Urban Parks

Urban parks are considered trip generators because in addition to serving as transportation facilities, parks serve as destinations themselves. Urban parks provide the most common location for leisure opportunities among residents, a place to participate in active and passive recreation activities outside the home. As a point of destination within the urban area, 70 percent of trips to urban parks are primary trips, which are made for the specific purpose of visiting these parks (Urbemis, 2002).

Depending on the size, the level of development, or the type of formal recreation available on the site, urban parks serve different segments of the population with unique recreation needs. Indeed, cities and regions often classify parks based on their general purpose, location and access level, and the character and extent of the development. Regional parks are often categorized as open space that attracts and serves people across the county or region, as well as outside areas. It may be developed for specific uses or have limits to access by fee or charge or by its distance from the user's residence. In contrast, local parks are intended to provide a variety of active or passive recreation opportunities, in close proximity to city residents and employment centers.

However, when these regional or district recreation areas are located in areas that are not accessible by walking, biking, or public transportation, such as those on the periphery of the urban area, the primary mode for accessing the park will be private automobiles. Recreation areas are significant generators of urban trips, particularly on off-peak and weekend time periods. Indeed, the San Diego municipal code estimates that an undeveloped park will generate 5 trips per day per acre of park, while a developed park generates approximately 50 trips per day per acre. By providing smaller, more diffuse areas for recreation located within the urban area, local parks can divert trips that would otherwise require a car and increase the share of non-motorized modes.

While some parks, such as regional parks, recreation facilities, and/or resource-based parks serve targeted recreation needs, providing a variety of recreation opportunities in locations where citizens live and work may reduce the number of automobile trips and vehicle miles of travel. These smaller urban parks tucked into the fabric of the surrounding community offer the opportunity for pedestrian-accessible recreation on a more frequent basis, diverting some trips to larger regional parks elsewhere in the urban area.

2.2.1 Definitions of Park Service Area

In order for urban parks to be established in the most pedestrian-accessible location, some cities have developed methods to determine the service area of potential and existing urban parks. A service area is the vicinity around a park within which someone could comfortably walk to access the facility. There are several approaches to determining an urban park's appropriate service area:

- The Container Approach: accounts primarily for the level of development density around each park (e.g., green space per capita)
- The Radius Technique: considers the spatial arrangement of amenities in the urban area based on a pre-determined buffer surrounding each park (e.g., quarter mile, half mile, etc.).
- The Catchment Approach: taking into

account both density and walkability by assigning every neighborhood to its nearest park using Thiessen (Voronoi) polygons

Explicitly accounting for distance, Sister et al. employed the radius technique, and demonstrated that only 14 percent of the Los Angeles region's population has pedestrian access to green spaces (i.e., 0.25 mi or 0.50 mi round trip). This leaves 86 percent of the population without easy access to such resources. When accounting for the effect of density—that is, defining access as the amount of green space per capita—predominantly White areas were shown to have disproportionately greater access. Latinos and African-Americans were likely to have up to six times less park acreage per capita compared to Whites (Sister et al., 2007).

Using "equity maps," Talen (1998) presented a framework for investigating spatial equity and demonstrated the use of GIS as an exploratory tool to uncover and assess current and potential future equity patterns. The study used ArcView to map out accessibility measures (i.e., gravity potential, minimizing travel cost, covering objectives, minimum distance), as well as socioeconomic data (i.e., housing values, percent Hispanic at the census block level) for a visual assessment of equity in the distribution of parks in Pueblo, Colorado. Reiterating the utility of equity maps as an exploratory tool, she presented a framework that utilized the visualization capabilities of GIS in mapping accessibility measures and demographic data such that planners can gauge (i.e., qualitatively) the degree of equity associated with any particular geographic arrangement of public facilities.

Of the 50 largest U.S. cities, only 18 have a goal for the maximum distance any resident should live from the nearest park — and among the 18, the standard ranged from as close as one-eighth of a mile to as far as a mile. Officials in cities with walkable park distance standards say that pedestrian accessibility is vital to reducing automobile trips and increasing physical fitness and general good health. They note that distances of over half a mile to a park result in people either skipping the trip or using their car to drive to the park (Harnik and Simms, 2004). At that point, the park has become a formal destination, not a place in the neighborhood to drop in.

2.2.2 Methods for Calculating Transportation GHG Mitigation

Calculating the level of automobile GHG emissions avoided or mitigated due to the presence of pedestrian-accessible urban parks requires knowledge or estimates of the number of park users and one of the approaches to calculating service area described above. Clearly, this is highly variable by city and regional recreation preferences, land-use densities, and geography. Estimates of the number of park users can be accomplished using census tract information for the surrounding area, or estimating an average park usage figure for a specific area based on socio-economic factors or surveys. Regardless of how an estimate of the number of users is derived, the following equation can be used to calculate the impact of one urban park on transportation-related GHG emissions.

ER = H * P * V * L * EF

Where:

ER = GHG emissions reduced

H = Households in the park service area

P = Percentage of households that visit a park

V = Average annual park visits per household

L = Average distance to next closest park

EF = Motor vehicle CO_2 emissions factor

The percentage of households that visit a park can be estimated in various ways, including use of bicycle/pedestrian factors associated with different types of surrounding land uses, studies of urban park projects, or regional household surveys. The

Fairfax County Park Authority in northern Virginia conducted a Park Needs Assessment in 2004 based on an extensive public input process that included stakeholder interviews, focus groups, public forums, and culminated in a community survey conducted with a statistically valid, random sample of Fairfax County households. The results of the survey and concurrent benchmark surveys in Montgomery County, Maryland, Wake County, North Carolina, Mecklenburg County, North Carolina, Mesa, Arizona and Johnson County, Kansas showed eight of every ten households had used the park system in the year leading up to the survey. Thus a conservative estimate of the percentage of households that visit a park in any urban area is 75 percent.

Estimates of the average annual park visits per household will vary according to local preferences, building patterns, and weather conditions. Therefore the most accurate estimates will be derived from local household surveys or usage statistics. A 2006 RAND study of urban parks in the Los Angeles region surveyed individuals at 12 neighborhood parks (n = 1,049) and residents living within a two-mile radius of each park (n = 849) and asked the question, "How often do you come to this park?" Approximately 83 percent of park users and 47 percent of residents indicated that they visited the park one or more times per week. Only 25 percent of all residents surveyed said that they never used the park. A conservative estimate of the average number of park visits per household is 4 visits per year.

2.2.3 A Case Study Urban Park: Oakland, CA

This example includes development of a small neighborhood park which included installation of play equipment, a track, and walking paths. The example is based on a project in the Oakland, California area. The new park is located within an existing neighborhood, which was previously served by a park located 2 miles away. The new park does not include space for a parking lot, but several bike racks are located at park entrances and it is assumed that most users will walk from the surrounding residential neighborhood. The parameters of the project consist of:

- 1,000 households in the park service area
- 75 percent of households currently visit a park
- 4 annual park visits per household
- 2 mile distance to next closest park

Step 1: Estimate the number of household auto trips diverted.

= (Households in the park service area) x (Percentage of households that visit a park) x (Average annual park visits per household)

= (1,000 households) x (75 percent park user rate) x (4 annual park visits per household)

= 3,000 auto trips

Step 2: Estimate the amount of VMT reduced.

= (Auto trips reduced) x (Average distance to next closest park)

= (3,000 trips) x (2 miles)

= 6,000 VMT

Step 3: Calculate annual emissions reduction.

= (Annual auto VMT reduced) x (Per mile CO_2 emission factor)

= (6,000 VMT) x 0.396 kg CO_2/mile

= 2,376 kg CO_2

= 2.4 MT CO_2

The estimates used in this example are rather conservative and should be replaced with better local data. As more neighborhood parks become available throughout an urban area, more and more of the population will have easy pedestrian access to these recreational facilities, and larger quantities of GHG emissions will be avoided.

2.3 Challenges and Uncertainties

To accurately assess the transportation-related impacts to GHG emissions for a particular parcel of land, or for a larger plan, the challenge lies in collecting information specific to that location. Many of the inputs used in the calculation methodologies discussed above are highly dependent on local conditions. With induced non-motorized transportation, average trip length, bikeway usage, and the number of automobile trips avoided necessitate local information, such as a user survey or other study. With the pedestrian-accessible urban parks, household park use and proper definition of the pedestrian-accessible park service area are the greatest sources for error. Park use rates may vary widely, while a given park may not reduce automobile trips if it does not meet the needs (playgrounds, playing fields, etc.) of the surrounding population. Furthermore, it is also possible that new parks may lead to a net increase in automobile trips. Ultimately, the dynamics of the other local parks, the transportation network, and surrounding land uses—especially housing density—will be the primary drivers behind any GHG benefits in this area.

3 Water Resources

3.1 Background

The delivery and treatment of water require a significant amount of energy. In California, two to three percent of all energy use is associated with the State Water Project (SWP), which supplies water to many communities and agricultural areas via complex, long-distance delivery systems from northern CA to southern CA (Wolff, 2005). Pumping and delivery of water accounted for 20,278 Gigawatt-hours (GWh), or approximately eight percent, of California's annual electricity use of 264,824 GWh in 2005 (California Energy Commission, 2006b). The water-related energy use is not evenly distributed throughout the state, however. In water districts that import much of their water supply from elsewhere in the state or from out of state, the energy use associated with obtaining water is much greater than for areas that are able to get water from local groundwater aquifers.

In one illustration of the contrast in energy use between importing and local pumping of groundwater, the energy required to deliver water from California's Imperial Irrigation District in southeastern California to the San Diego County Water Authority is 2,110 kWh per acre-foot (AF) of water (Wolff, 2005) while the average energy required to pump groundwater in California is 1.46 kWh per AF per foot of lift (at an assumed 70 percent efficiency). The average depth to groundwater varies throughout the state. For example, in the Tulare Lake area the average well depth is 120 feet, so pumping groundwater there requires about 175 kWh of energy per AF; the Central Coast area has an average well depth of 200 feet, so this requires 292 kWh per AF of water (California Energy Commission, 2008). The energy required to pump groundwater in Los Angeles is higher at 580 kWh/AF, but the energy required to deliver water to southern California via the SWP is as much as 3,236 kWh per AF (NRDC, 2004). The current dearth of viable groundwater in some areas necessitates the delivery of water from out of state or from water-rich areas in-state; an increase in the availability of local groundwater resources would reduce the reliance on imported water and could contribute to a decrease in electricity consumption.

This electricity consumption indirectly results in GHG emissions due to fossil fuels that are often used to generate that electricity. The rate of GHG emissions per unit of electricity generated, or the CO_2 emission factor, depends on the mix of fuels used to supply the electricity grid, a mix that varies

throughout the United States. The more coal, oil, and natural gas that are used in electricity generation, the higher the CO_2 emission factor. The more that sources that don't emit GHGs are used—sources such as nuclear, wind, hydro, geothermal, and others—the lower the CO_2 emission factor. Technology plays a role, as older coal-fired plants are far more carbon-intensive than plants built today. Further complicating the issue, the grid mix can vary widely by the time of year (hydro, wind, and solar are susceptible to seasonal variations) and by time of day, as plants are brought on- and off-line during the day to meet peak demand. On top of all these variations, the interconnected nature of the electricity grid means that it is extreme difficult to precisely know the fuel source of one's electricity. Therefore, it is best to use an average regional or power pool emission factor. The California Climate Action Registry's General Reporting Protocol suggests using either a verified emission factor reported under the Registry's Power/Utility Protocol or power-pool based factors from the US EPA's eGRID database (CCAR, 2008). [4]

On the national level, over half of all electricity is generated using coal, while nuclear energy (20 percent) and natural gas (17 percent) follow, resulting in an average emission rate of 0.613 kg CO_2/kWh, yet this grid mix varies greatly by region (EPA, online 2008). Energy supplied to the electrical grid sub-region for much of California (CAMX) is dominated by natural gas (46 percent), with large amounts of hydropower (15 percent), nuclear energy (14 percent), and coal (13 percent), for an average emission rate of 0.399 kg CO2/kWh (EPA, online 2008). Because the CAMX sub-region represents almost all of the electricity consumed in California (including hydropower from the Pacific Northwest and coal power from Utah), it is a better gauge than the California statewide grid mix, which only includes electricity generated within the state. The Los Angeles Department of Water and Power fuel mix again differs from the CAMX sub-region. The fuel mix relies more on coal and less on natural gas, hydropower, and nuclear power than the rest of the state. As a result, its average emission rate is higher at 0.562 kg CO_2/kWh (LADWP, online 2008). The grid mixes and emission rates for these three examples are provided for comparison in Table 3 below.

Table 3: Resource Mixes for the United States, California Sub-region (CAMX) and Los Angeles Department of Water and Power (DWP)

Fuel Source	US Average Grid Mix	CAMX Grid Mix	Los Angeles DWP Energy Resource Mix
Natural Gas	17.4	46.4	32
Hydro	6.6	15.1	12
Nuclear	20	14.2	9
Coal	50.2	12.6	44
Geothermal	0.3	4.7	<1
Biomass	1.4	2.8	1
Wind	0.34	2.01	2
Oil	3	1.1	N/A
Other Fossil Fuel	0.5	0.9	N/A
Solar	0.015	0.267	<1
CO2 Emissions Factor	0.613 kg/kWh	0.399 kg/kWh	0.562 kg/kWh

Source: EGrid (www.epa.gov/solar/energy-resources/egrid/); Los Angeles Department of Water & Power, Power Content Label. www.ladwp.com/ladwp/cms/ladwp000536.jsp

[4] Available online at www.epa.gov/cleanenergy/energy-resources/egrid/index.html.

3.1.2 Water resources and Green Space

The expansion of green spaces in urban areas has been identified as a pathway for reducing the energy use and CO_2 emissions associated with water delivery by providing a medium for wastewater recycling and increased stormwater retention (Anderson, 2003; Kramer and Dorfman, 2000). The most direct and quantifiable impact on water resources is through the increase in groundwater recharge that is associated with the high permeability of green spaces, compared with the low permeability surfaces of densely developed areas. The permeability of a surface, by definition, indicates its ability to infiltrate water, primarily in the context of rainwater. A surface with a high permeability is able to infiltrate more water into the soil below than is a surface with a low permeability. After water infiltrates the surface cover, it continues through the unsaturated zone of soil, and can potentially reach the local groundwater aquifer (Chralowicz, et al., 2001). When the intensity of a rainfall event exceeds the ability of a surface to infiltrate water, stormwater runoff is created. Water becomes runoff by accumulating on a surface, moving over land, and then traveling down slope (Chralowicz, et al., 2001). Increased runoff is linked to increased entry of nonpoint source pollution into water bodies, localized urban flooding, and the loss of water that could otherwise be available as a water supply, such as with groundwater recharge through permeable surfaces.

3.2 Estimating the Benefit to Water Resources from Green Space

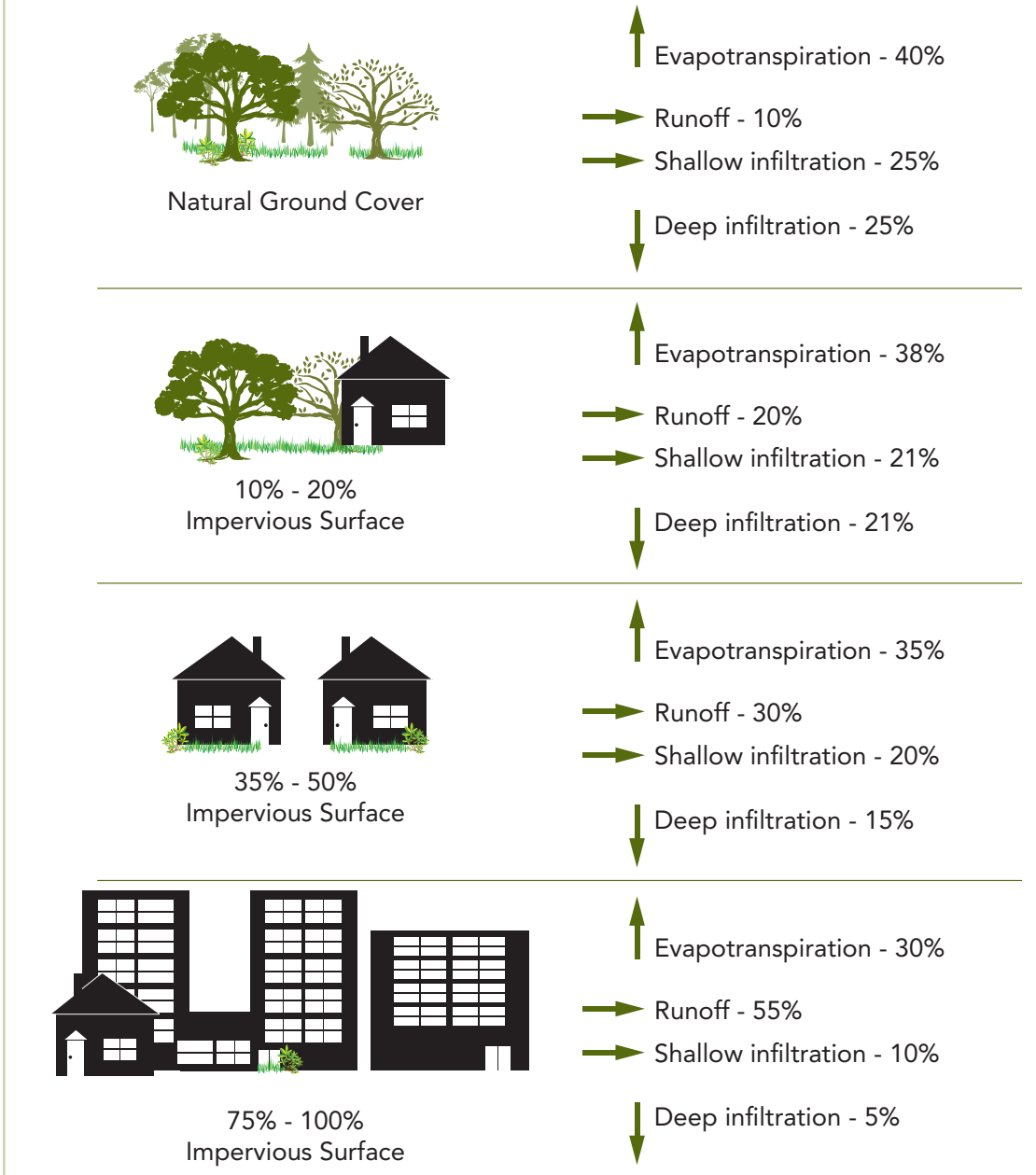
A dense urban area can have more than 90 percent of its land covered with low permeability surfaces. In areas with largely-impervious surfaces covering 75 to 100 percent of the land, only 15 percent of water is infiltrated through the surface down to the soil, with only five percent deep infiltration (potentially recharging groundwater) (see Figure 1). Storm runoff in urbanized areas can increase two to 16 times over that of undeveloped land, "with proportional reductions in groundwater recharge" (FISRWG, 1998). A two inch rainfall event on land with moderately permeable soils that is developed commercially would produce 1.4 inches of runoff; if developed with ¼ acre residential lots, 0.9 inches of runoff (USDA, 1986). The surface cover is not the only factor in determining runoff potential. The amount of runoff generated is dependent on the type of soil in the area. In order to calculate the expected runoff for an area, the following definitions can aid in determining the soil type (USDA, 2007).

- Group A: Low runoff potential when saturated; water is transmitted freely through soil; less than ten percent clay and more than 90 percent sand or gravel;
- Group B: Moderately low runoff potential when saturated; water transmission through soil unimpeded; ten to 20 percent clay and 50 to 90 percent sand; loamy sand texture;
- Group C: Moderately high runoff potential when saturated; water transmission through soil is somewhat restricted; 20 to 40 percent clay and less than 50 percent sand; textures may be loam, silt loam, sandy clay loam, clay loam; and
- Group D: High runoff potential when saturated; water transmission through the soil is restricted to very restricted; more than 40 percent clay, less than 50 percent sand; texture is clayey; some areas have a high shrink-swell potential.

A two inch event on undeveloped land with moderately permeable soils that has, for example, native wood grasses, the runoff produced is approximately only 0.3 inches (USDA, 1986). On average, natural ground cover allows 50 percent of stormwater to infiltrate the surface, with 25 percent infiltrating deeply with the potential to recharge groundwater (FISRWG, 1998). The remaining forty percent is accounted for through the processes of evaporation and use by plants and trees, collectively referred to as evapotranspiration (see Figure 1 below).

If a planner were interested in comparing the difference in hydrology for two land use options, the runoff for both options can be calculated for different rainfall event scenarios using the local soil group and surface cover, Table 4, and Table 5. This calculation will form the basis of further steps in estimating GHG reductions. An example calculation follows:

Figure 1: Relationship between impervious cover and surface runoff



Source: FISRWG, 1998.

Method: Determining runoff for a particular location, land use, and rainfall event

1. Find the appropriate surface cover type (Table 4)
2. Extract the curve number (CN) from the table, using the column for the local soil group (A,B,C,D) [5]
3. Lookup the CN in in Table 5
4. In "Rainfall" column, look up the desired rainfall event (inches)
5. Using rainfall event amount and CN, determine the expected runoff for a specific event and land cover
6. In "Rainfall" column, look up the desired rainfall event (inches)
7. Using rainfall event amount and CN, determine the expected runoff for a specific event and land cover

Example: Evaluating land use options, accounting for hydrologic factors

- Land Use Option 1 = Residential Lots, ¼ acre; Soil Group B; Event Rainfall: 2.5 inches
  1. Look up "Residential districts by average lot size: ¼ acre" in Table 4
  2. Follow row across to CN column for soil group B; CN = 75
  3. Lookup CN =75 in Table 5
  4. In Rainfall column, look up event "2.5 inches"
  5. Match 2.5 inch rainfall and CN of 75 on the grid in Table 5. Expected runoff for this event is 0.65 inches
- Land Use Option 2 = Neighborhood Park; Soil Group B; Event Rainfall: 2.5 inches
  1. Look up "Open space: good condition (grass cover > 75 percent)" in Table 4
  2. Follow row across to CN column for soil group B; CN = 61
  3. Lookup CN = 61 in Table 5
  4. In Rainfall column, look up event "2.5 inches"
  5. Match 2.5 inch rainfall and CN of 61 on the grid in
  Table 5. Expected runoff for this event is 0.20 inches

Result: The expected difference to the amount of runoff produced is 0.45 inches. (Using the land for ¼ acre residential lots would result in 0.45 inches more runoff than would a neighborhood park, in the event of a 2.5 inch rainfall.)

The benefit to water resources is dependent on the spatial area and the "type" of green space. If the primary purposes of adding green space are to aid in water conservation, mitigation of the urban heat island effect, and the reduction of greenhouse gases, a larger fraction of the ground cover should be highly permeable surfaces. Urban green spaces with less permeable surfaces include plazas (less than ½ acre, low permeability, and low plant diversity) and business parks (more than five acres, moderate permeability, and low plant diversity). More hydrologically-beneficial urban green spaces include community gardens (less than two acres, no impervious surfaces, with planted landscaping), stormwater ponds/wetland buffers (less than five acres, no impervious surfaces, with native plants and animals), and neighborhood parks (less than 25 acres, high permeability, and limited plant diversity) (DCAUL, 2003). Additional technical guidance for parcel screening and analysis, including runoff calculations, acreage requirements, and locale prioritization is provided in CCI, 2008 (The green solution project: creating and restoring park, habitat, recreation and open space on public lands to naturally clean polluted urban and stormwater runoff).

[5] The curve numbers listed in Table 4 have been in use since the 1950s and were slightly modified in 1986 (USDA, 1986); because most surfaces and soil types have the same general properties now as they did then, and today's curve number methodology is not drastically different, an updated curve numbers table has not been released. The recent introduction of more porous, runoff-reducing, paving materials can change the curve number equations. For the most accurate curve number for a particular paving material, the manufacturer can provide curve numbers for the pavement with different soil groups. Using the manufacturer-provided curve number in the runoff calculation example in section 3.2, skip to step 4.

In addition to the natural, inherent benefits to water resources of adding more green space to an urban area, technology to maximize the ability of these spaces to reduce runoff and increase groundwater recharge is being implemented. Some municipalities have added subsurface equipment to first separate sediment, pollutants, and trash from stormwater, and subsequently store the water in large chambers, which gradually release the water into the soil to prevent the oversaturation of soils, thus minimizing runoff and maximizing aquifer recharge. This method is referred to as "bioretention." For even more efficient collection and retention of water for groundwater recharge, green space could be planned in areas that naturally receive runoff from surrounding land, such as in a basin; at the base of a hill; or adjacent to a river. In other areas, stormwater is collected and used for park irrigation; while not recharging groundwater, it still prevents the usage of additional water for irrigation. It is also important to note that in some areas, projections, and early observations of, climate trends over the 21st century include increased severity of individual heavy rainfall events (Groisman, et al., 2005). The collection of stormwater during these heavy flash events could provide an even more substantial contribution to groundwater recharge and prevent the entry of additional non-point source pollutants into surface water sources. On a small scale, individual bioretention systems can be implemented on a particular parcel of land, such as at a neighborhood park, school campus, or business park. It is also possible to create a larger bioretention system, covering a drainage area of up to several hundred acres (CCI, 2008).

Table 4: Runoff Curve Numbers for Urban Areas

Cover Description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	**Average percent impervious area**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.):					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

Table 5: Runoff Depth for Specified Curve Numbers in Urban Areas

Rainfall	Runoff depth for curve number of:												
(inches)	40	45	50	55	60	65	70	75	80	85	90	95	98
1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.08	0.17	0.32	0.56	0.79
1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.15	0.27	0.46	0.74	0.99
1.4	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.13	0.24	0.39	0.61	0.92	1.18
1.6	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.20	0.34	0.52	0.76	1.11	1.38
1.8	0.00	0.00	0.00	0.00	0.03	0.09	0.17	0.29	0.44	0.65	0.93	1.29	1.58
2.0	0.00	0.00	0.00	0.02	0.06	0.14	0.24	0.38	0.56	0.80	1.09	1.48	1.77
2.5	0.00	0.00	0.02	0.08	0.17	0.30	0.46	0.65	0.89	1.18	1.53	1.96	2.27
3.0	0.00	0.02	0.09	0.19	0.33	0.51	0.71	0.96	1.25	1.59	1.98	2.45	2.77
3.5	0.02	0.08	0.20	0.35	0.53	0.75	1.01	1.30	1.64	2.02	2.45	2.94	3.27
4.0	0.06	0.18	0.33	0.53	0.76	1.03	1.33	1.67	2.04	2.46	2.92	3.43	3.77
4.5	0.14	0.30	0.50	0.74	1.02	1.33	1.67	2.05	2.46	2.91	3.40	3.92	4.26
5.0	0.24	0.44	0.69	0.98	1.30	1.65	2.04	2.45	2.89	3.37	3.88	4.42	4.76
6.0	0.50	0.80	1.14	1.52	1.92	2.35	2.81	3.28	3.78	4.30	4.85	5.41	5.76
7.0	0.84	1.24	1.68	2.12	2.60	3.10	3.62	4.15	4.69	5.25	5.82	6.41	6.76
8.0	1.25	1.74	2.25	2.78	3.33	3.89	4.46	5.04	5.63	6.21	6.81	7.40	7.76
9.0	1.71	2.29	2.88	3.49	4.10	4.72	5.33	5.95	6.57	7.18	7.79	8.40	8.76
10.0	2.23	2.89	3.56	4.23	4.90	5.56	6.22	6.88	7.52	8.16	8.78	9.40	9.76
11.0	2.78	3.52	4.26	5.00	5.72	6.43	7.13	7.81	8.48	9.13	9.77	10.39	10.76
12.0	3.38	4.19	5.00	5.79	6.56	7.32	8.05	8.76	9.45	10.11	10.76	11.39	11.76
13.0	4.00	4.89	5.76	6.61	7.42	8.21	8.98	9.71	10.42	11.10	11.76	12.39	12.76
14.0	4.65	5.62	6.55	7.44	8.30	9.12	9.91	10.67	11.39	12.08	12.75	13.39	13.76
15.0	5.33	6.36	7.35	8.29	9.19	10.04	10.85	11.63	12.37	13.07	13.74	14.39	14.76

Source: USDA, 1986.

The replacement of impenetrable surfaces with green spaces can have significant impacts on the need to import water, the associated energy use, and CO_2 emissions. However, in order to see the full energy savings benefit associated with reducing water imports, a municipality-wide policy decision to reduce reliance on imported water is needed. If an overall water-savings plan is not in effect, any reduction in the need to import water in one location could simply be made up elsewhere within the water district.

3.3 Urban Water Use/Reuse Planning: Los Angeles

Currently, the groundwater aquifer below Los Angeles has 2,000,000 AF of capacity available. A watershed "makeover" plan has been designed for the Los Angeles basin, based on the premises of expanding permeable surface area and redesigning the remaining impermeable surfaces to guide stormwater runoff into designated systems for reuse and groundwater recharge. The plan estimates that Los Angeles could cut water imports by 50 percent by 2020, reduce flooding, and create 50,000 jobs (TreePeople, online 2008).

In 2007, Los Angeles imported about 45 percent (301,500 AF) of its 670,000 AF of water from the Metropolitan Water District of Southern California (MWDSC). Using the figures for energy use and CO_2 emissions estimates for imported water [6] for the MDWSC, the energy required to import water was approximately 975,654,000 kWh (using the Los Angeles resource mix), resulting in emissions of 548,318 metric tons of CO_2. An example equation used to estimate the GHG emissions associated with imported water is as follows:

[6] 45 percent, or 301,500 AF, of the 670,000 AF of MDWSC water is imported annually. At the energy cost of 3,236 kWh/AF of imported water, total energy used is 975,654,000 kWh each year.

$C_i = Wi \times Ei \times EFc$

Where:

C_i = Total CO_2 emissions due to importing water to the water district, annually

W_i = Water imported, annually;

E_i = Energy used to import water, per AF;

EF_c = CO_2 emissions factor; and

For the Los Angeles example:

C_i = 301,500 AF x 3,236 kWh/AF x 0.562 kg CO_2/kWh = 548,317,548 kg CO_2

C_i = 548,3175 metric tons CO_2

If the "makeover" plan were to be enacted, and if the estimates for decreased import reliance are correct, the reduction in CO_2 emissions could be as much as 215,000 metric tons, annually, after correcting for the energy required to pump groundwater [Energy to pump groundwater = 301,500 AF x 0.6 (accounting for 40 percent loss to evapotranspiration) x 580 kWh/AF x 0.562 kg CO_2/kWh = 58,966 metric tons CO_2]. An increase in urban green space can play a critical role in achieving these reductions in energy use. Currently, the Lower Los Angeles River watershed is estimated to have an average imperviousness of 52 percent (CCI, 2008). In an effort to help determine the best locations for hydrologically-beneficial green space in Los Angeles County, Community Conservancy International (CCI) has produced a map of public parcels, highlighting their proximity to water features. The LA County map can be found at http://www.ccint.org/greensolution.html, along with similar maps for the Santa Monica Bay watersheds, Los Angeles River watershed, San Gabriel River watershed, Dominguez Channel watershed, and the Santa Clara River watershed.

In addition to the increased recharge of stormwater, green spaces can also be used as sites for recycling of local wastewater. If designed to infiltrate the space at the appropriate rate for the soil and ground cover type, none of the water should be lost to runoff, but up to 40 percent of the water could be excluded from groundwater recharge due to evapotranspiration. Continuing to use Los Angeles as an example, it is estimated that the Bureau of Sanitation (BOS) produces 518,560 AF of highly treated wastewater per year. The city has been using recycled water since 1979 for irrigation and industry. The city acknowledges the need for recycled water for groundwater recharge, but specific plans have not come to fruition. The goal is for six percent of the total water demand to be recycled by 2019. The current total water demand is approximately 670,000 AF per year, with the demand growing at approximately 0.4 percent each year (City of Los Angeles, 2008). At the current rate of growth, water usage will be at 1,072,700 AF per year by 2019; if the six percent recycling goal is realized by 2019 as planned, 64,362 AF will be available for recycling (with the city hoping for 15,000 AF of that to go to groundwater recharge) (City of Los Angeles, 2008).

Looking only at the savings in energy that are related to replacing imported water with groundwater (losses from inefficiency are already factored in to the kWh/AF estimates for each, but evapotranspiration needs to be recognized):

1. $W_g = W_g - (Wr \times ET)$
2. $E_{it} = W_i \times E_i$
3. $E_g = W_g \times E_p$
4. $E_s = E_{iT} - E_g$
5. $C = E_s \times EF_c$

Where:

W_g = Groundwater pumped;

W_r = Water recycled into green space (AF);

ET = Evapotranspiration (%);

E_{iT} = Total energy used to import water (kWh);

W_i = Water imported (AF);

E_i = Energy to import water, per AF (kWh);
E_g = Total energy used to pump groundwater (kWh);
W_g = Groundwater pumped (AF);
E_p = Energy to pump groundwater, per AF (kWh);
E_s = Energy saved by pumping groundwater, rather than importing (kWh)
C = CO_2 emission savings from pumping groundwater, rather than importing water (metric tons); and
EF_c = CO_2 emissions factor (kg CO_2/kWh)

To continue with the Los Angeles example:

W_g = 15,000 AF – (15,000 x 40%) = 9,000 AF
E_g = 9,000 AF x 580 kWh/AF = 5,220,000 kWh
E_{iT} = 9,000 AF x 3,236 kWh/AF = 29,124,000 kWh
E_s = 29,124,000 kWh – 5,220,000 kWh = 23,904,000 kWh
C = 23,904,000 kWh x 0.562 kg CO_2/kWh = 13,434,048 kg CO_2
C = 13,434 MT CO_2 [savings from pumping groundwater]

3.4 Case Studies

While the above example demonstrates Los Angeles' citywide goal, the following examples demonstrate how to calculate the project-level benefits.

3.4.1 Broadous Elementary School, Pacoima, CA

The Broadous Elementary School campus in Pacoima, CA had historically experienced periodic flooding that at times was so disruptive that it reduced school attendance by 15 percent. As part of the Department of Water and Power's (DWP) Cool Schools initiative, the school district allowed DWP and TreePeople, a nonprofit organization that educates communities and government about the benefits of sustainable solutions to ecosystem problems, to use the school as the site of a demonstration in sustainable design. The partners saw the flooding problem on the 7.4 acre campus as an opportunity to restore the site function to its natural state via removal of "impenetrable surfaces and creating a campus 'forest' capable of intercepting and absorbing rainfall" (TreePeople, 2007).

In addition to the mitigation of flooding the objectives of the project include:

- Creating natural space for outdoor learning and playing;
- Increase green space by replacing 1/3 of paved areas with a ball field, trees, and landscaping;
- Collect, treat, and store stormwater for gradual infiltration into soil; and
- Groundwater recharge.

In 2001, the site was redesigned to capture almost all of the rain that falls on campus. Much of the previously paved areas were landscaped with trees and other permeable groundcover; one third of the paved area was replaced with vegetation. Canopy cover on campus increased from nine to 16 percent. Paved areas are now sloping away from the school and guide runoff into the stormwater capture system. The design of the stormwater system is based on three components: a swale, a stormwater separator, and an infiltration basin. The swale, referred to as the Broadous River, is a vegetated strip that begins on a grassy hill and mimics the shape of a meandering river, flowing through campus.[7] This acts to slow runoff from paved areas and begins the process of cleaning the water simply with its filtration through the soil. Water from the

[7] The Broadous Elementary example is also a good illustration of the importance of operations and maintenance (O&M). Currently, the school is not experiencing the full stormwater collection benefit. A lack of O&M has led to a modification of the original design. While many of the components are still in place, the vegetated swale has been replaced with a paved area (The River Project, 2006).

swale and from paved areas all flows in the separator, a treatment mechanism, which removes some pollutants and trash from the stormwater before it moves to the infiltration system. The infiltration system consists of 200 plastic chambers, which temporarily hold the water and then slowly release it for slow percolation through the soil. The infiltration system used at Broadous Elementary is the Vortechs 9000 (TreePeople, 2007).

At any time, the infiltrator units can collectively hold up to 95,200 gallons of water (0.3 AF). This system was designed to collect 100 percent of the expected runoff from a ten year rainfall event. The separator and infiltration systems are both located under a playing field, which replaced an asphalt surface (TreePeople, 2007). The estimated cost for the school system each year for maintenance and inspection of the systems is approximately $4,500.

Using 46 years of rainfall data, the benefit of the system was calculated. Prior to the campus redesign, annual runoff was approximately 126,000 cubic feet. After the redesign, runoff was reduced by 99.9 percent to about 126 cubic feet. Additionally, post-design monitoring indicates that E. coli and fecal coliform were significantly lower in lysimeter (24 ft below ground) and groundwater samples than in surface stormwater (TreePeople, 2007). If the infiltrator prevents much of the loss to shallow infiltration and evapotranspiration and fosters the entry of approximately 95 percent of the water (120,000 cubic feet) into the groundwater aquifer, we can calculate the savings in energy and CO2 emissions:

Conversion of cubic feet to acre-feet ⇨1 CF = 2.3×10^{-5} AF

W_i = Water imported (AF)

E_i = Energy to import water (kWh)

E_g = Total energy used to pump groundwater (kWh)

W_g = Groundwater pumped (AF)

E_s = Energy saved by pumping groundwater, rather than importing (kWh)

C = CO2 emission savings from pumping groundwater, rather than importing water (metric tons)

EF_c = CO2 emissions factor (kg/kWh)

W_g = 120,000 CF x 2.3×10^{-5} AF/CF = 2.76 AF

E_i = 2.76 AF x 3,236 kWh/AF = 8,931 kWh

E_g = 2.76 AF x 580 kWh/AF = 1,601 kWh

E_s = 8,931 kWh – 1,601 kWh = 7,330 kWh

C = 7,330 kWh x 0.562 kg/kWh = 4,119 kg

C = 4.11 metric tons of CO_2 emissions, annually

Other than the energy saving benefits related to stormwater collection at Broadous Elementary, benefits of adding the green space include mitigation of the heat island effect from the paved areas surrounding the schools. The addition of over 170 trees to the campus has assisted in providing shade for the buildings and lowering the heat retention associated with paved surfaces; these changes are expected to result in up to 18 percent savings in energy use. Collection of the tree waste, such as leaves and clipping, for use as mulch also assists in reducing the need for irrigation; the mulch acts to reduce evaporation around the base of the trees and other plants.

3.4.2 Land Use Planning: Urban Park vs. Townhouse Development

In urban areas with water-related concerns, such as nonpoint source pollution and water supply shortages, it is ever more likely that the water implications are considered when determining how to develop or redevelop a parcel of land. Although indirect, water-conscious decision-making in planning can also contribute to a reduction in CO2 emissions. Many cities, including Chicago, Portland, Seattle, Minneapolis, and Milwaukee, are making modifications to their long-term planning goals by including green spaces in the design of public parks, streets, and even on rooftops. These cities, and others, also provide tax incentives to private citizens for those that include sustainable green design in remodeling and new construction.

In addition to the reductions in CO2 emissions associated with the carbon sequestration benefit of vegetation, mitigation of the urban heat island effect, and encouraging reducing vehicle travel with pedestrian-friendly zones, an additional indirect benefit is via the increased groundwater recharge and reduced stormwater runoff. Although there are additional benefits to having less runoff, such as reduction in water pollution and flooding, here we consider only the implications for CO2 emissions.

Calculating the reduction in CO2 emissions

For a two acre parcel of land in San Diego County, California that is currently undeveloped, for example, a planner could make several calculations to determine the water and associated CO2 emissions benefits that are expected by choosing to use the two acres as a neighborhood park that has a permeable surface over 90 percent of its surface area, rather than designating the land for townhouse development on 1/8 acre parcels.

The park can be designed such that even its impermeable surfaces, such as pedestrian walkways or bike paths, gently slope toward more permeable surfaces to minimize runoff and maximizing groundwater recharge. In a traditionally-designed townhouse development, 65 percent of its surfaces will be impermeable. In this hypothetical scenario, the soils in the area belong to soil group B, which is porous and somewhat sandy and has moderately low runoff when saturated. Using the calculations provided here, we can determine the expected groundwater runoff, groundwater recharge, and the associated reduction in imported water and CO2 emissions.

Calculation for a 2 inch rain event

- Land Use Option 1 = Townhomes, 1/8 acre; Soil Group B; Event Rainfall: 2 inches
  1. Look up "Residential districts by average lot size: 1/8 acre" in Table 4
  2. Follow row across to CN column for soil group B; CN = 85
  3. Lookup CN =85 in Table 5
  4. In Rainfall column, look up event "2 inches"
  5. Match 2 inch rainfall and CN of 85 on

the grid in Table 5. Expected runoff for this event is 0.80 inches

- Land Use Option 2 = Neighborhood Park; Soil Group B; Event Rainfall: 2 inches
  1. Look up "Open space: good condition (grass cover > 75%)" in Table 4
  2. Follow row across to CN column for soil group B; CN = 61
  3. Lookup CN = 61 in Table 5
  4. In Rainfall column, look up event "2 inches"
  5. Match 2.5 inch rainfall and CN of 61 on the grid in Table 5. Expected runoff for this event is 0.07 inches

Result: The expected difference to the amount of runoff produced is 0.73 inches. To calculate the difference between the land use choices in the total quantity of runoff from this event: 0.73 inches (0.061 feet) x 2 acres = 0.122 AF less runoff for neighborhood park for a 2 inch event.

Calculation for runoff in an example year with three 1", one 1.2", and two 2" events

- Land Use Option 1 (Townhomes)
  1. Estimate runoff from rainfall events for the year, using Table 4 and Table 5
  2. Runoff = (3 x 0.17") + (0.27") + (2 x 0.80) = 2.38"
  3. Runoff = 0.198 feet of runoff x 2 acres = 0.397 AF
- Land Use Option 2 (Neighborhood Park)
  1. Estimate runoff from rainfall events for the year, using Table 4 and Table 5
  2. Runoff = (3 x 0") + (0.0") + (2 x 0.07) = 0.14"
  3. Runoff = 0.012 feet of runoff x 2 acres = 0.024 AF

With Land Use Option 1, the expected groundwater recharge is about 5 percent (see Figure 1). Over the course of this example year, groundwater recharge would be approximately = 0.41 inches (0.034 feet) water x 2 acres = 0.068 AF groundwater recharge. With Land Use Option 2, the expected groundwater recharge is about 25 percent (see Figure 1). Over the course of this example year, groundwater recharge would be approximately = 2.05 inches (0.171 feet) water x 2 acres = 0.342 AF groundwater recharge. The difference between these two scenarios is 0.342 AF – 0.068 AF = 0.274 AF. Since this is a reduction in the amount of water that needs to be imported, the emissions savings can be calculated as follows:

E_i = Energy to import water (kWh) = 3,240 kWh/AF (NRDC, 2004)
E_g = Total energy used to pump groundwater (kWh) = 570 kWh/AF (NRDC, 2004)
W_g = Groundwater pumped (AF) = 0.27 AF
EF_c = CO2 emissions factor (kg/kWh) = 0.399 kg CO_2/kWh (CAMX average)

W_g = 0.27 AF
E_i = 0.27 AF x 3,240 kWh/AF = 875 kWh
E_g = 0.27 AF x 570 kWh/AF = 154 kWh
E_s = 875 kWh – 154 kWh = 721 kWh
C = 721 kWh x 0.399 kg/kWh = 288 kg

C = 0.3 metric tons of CO_2 emissions, annually

While this amount is modest, with more thorough rainfall event estimates the annual savings are likely to increase. When compared with the Broadous School example however, it is clear that using technology to enhance groundwater recharge will increase the GHG savings to be realized.

3.5 Challenges and Uncertainties

When determining the energy-saving benefits related to water resources, the largest technical challenge may be in collecting the correct data for the water-savings calculations. For example, to accurately determine groundwater recharge at a particular location, knowledge of the soil type, annual precipitation patterns, and electricity grid mix are required. Also required is information about the type of vegetation to be used, along with the expected irrigation requirements. Unpredictable variability in the calculation components can also present challenges for accurate calculation of benefits to GHGs. Some of the variables in the energy-saving calculations are, in practice, not highly predictable; even if accurate information about the particular location is collected in advance of the park development, the savings could be greater than or less than what is estimated by initial estimates. For example, if proper O&M is not conducted at the site; rainfall for a particular year is much different than the historical climatology would indicate; municipal water policy changes after park development; or if the emissions from electricity generation change over time, many of the initial assumptions might not apply. In addition it should be noted that the beneficial impacts of groundwater recharge for a location are only likely to be realized upon larger policy decisions to reduce reliance on imported water. If supplementary groundwater recharge results in greater use of groundwater in addition to the unimpeded use of imported water, there will not be a reduction in CO2 via decreased energy consumption.

4 Urban Parks and Trees: Carbon Sequestration and Energy Benefits

The planting of trees as a part of urban park development can be effective at sequestering carbon dioxide and reducing local energy consumption. As trees grow, they remove carbon dioxide from the atmosphere and store it in the form of biomass carbon in the leaves, roots, branches, and trunk. The amount of carbon that a tree sequesters annually is based on a number of factors, the most significant of which are age and tree species. A young sapling can sequester anywhere from 1.0 to 1.3 lbs. carbon each year, while a 50 year old tree can sequester over 100 lbs. annually (DOE, 1998).

With the sequestration of many trees put together, urban trees can be a significant sink for carbon dioxide. The rate of net sequestration per area of tree cover can be as high as 0.29 kg C/sq. m tree cover (EPA, 2008). Indeed, the sequestration by urban trees in the city of New York is estimated to be 38,374 MT annually, and other cities can also claim similar GHG benefits. In total, urban trees in the US sequestered an estimated 95.5 MMTCO2 in 2006 (EPA, 2008).

This area has been widely researched. Among other organizations, the Center for Urban Forest Research and the United States Forest Service have conducted studies on the carbon sequestration of urban trees. The information from these studies can provide perspective on estimating the potential carbon sequestration that a planned park could provide, and it can help estimate the carbon sequestration of existing parks as well, and with better accuracy.

In addition to carbon sequestration, wood waste and tree trimmings from urban parks can be used as feedstock for facilities that generate electricity using biomass. Carbon dioxide emis-

sions from such facilities are not counted as GHG emissions because the carbon emitted would be biogenic and not derived from fossil fuels. Some studies have begun to look at the potential for GHG savings when implemented on a statewide basis (Winrock, 2004), but there are significant challenges to accurately estimating the GHG benefits of this practice. The GHG reductions due to reduced reliance on fossil fuels may be offset by the emissions associated with trimming, collection, and transportation to a biomass facility. While there are potential benefits, this issue will require further research.

4.1 C Sequestration by Established Parks

Numerous methodologies exist for estimating carbon sequestration by existing urban trees and parks. These methodologies are developed specifically for urban trees, which have different growth and management patterns from forestland. On an aggregated level, the national Inventory of U.S. Greenhouse Gas Emissions and Sinks utilizes data obtained from remote sensing to estimate urban tree coverage in the U.S., and then applies an average sequestration rate to this canopy cover (EPA, 2008). This rate is derived from field studies conducted in individual cities.

Alternatively, C sequestration for a given urban park can be estimated by tree measurement conducted in the field. The California Climate Action Registry and USDA Forest Service have jointly developed a methodology that builds on measurements of tree height and diameter (CCAR, 2008a). Using equations from a UNFCCC protocol on settlement afforestation (UNFCCC, 2007), biomass is calculated for each tree. Carbon stock is then calculated using a conversion from biomass to stored carbon. The difference in calculated carbon stock from year to year provides sequestration values. This protocol estimates the C stock of standing live trees, excluding soil, debris, and shrubs – an approach that is largely consistent with the national inventory. In addition, this protocol provides measurement guidelines for the collection of tree data. While this methodology can provide a very accurate estimate, specific to each tree, it involves measurements than can clearly become time-intensive for a large set of trees. The Center for Urban Forest Research has developed a software tool, called CTCC, which allows a user to conduct this same methodology electronically (CCAR, 2008a).

Rather than recreate the method here, it is recommended that users consult this highly-developed tool for estimating benefits for their parks. However, since this method is based on the use of field measurements, it is not possible to apply this method to parks that do not exist.

4.2 C Sequestration by Planned Parks

Projecting carbon sequestration for a planned urban park presents a different set of challenges. Methodologies have been developed to estimate the amount of carbon that an urban park will sequester in the future. In this case, the data needed include: the number and species to be planted, and the size of the trees at time of planting. Additional information can be used to make the estimate more accurate.

The Department of Energy developed an easy to use approach for sequestration estimation (DOE 1998). Data on the species of trees planted and sapling ages is used in order to develop sequestration estimates for each year of the tree's future life. First, the number of trees of each species to be planted must be known, in addition to their age at the time of planting. Each species is then mapped to a growth category – slow, moderate, or

fast – and to either a type – hardwood or conifer (see Table A- 1). This information is then used to identify a carbon sequestration rate and a survival factor for each, for each year of the lifetime of the tree (see Table A- 1). Thus, the average sequestration rate, weighted by its survival factor, can be calculated. The equation is as follows:

> Carbon sequestered (lbs/year) = Annual sequestration rate from Table A- 2 * Number of trees planted at Age 0 (adjusted for nonstandard planting size) * Survival factor from Table A- 2

Trees planted at nonstandard sizes need to be adjusted for age. This methodology uses the definition that a tree is at age 0 at the standard planting size – in a 15 gallon container or in burlap, approximately 1" in diameter at 4.5 above the ground when planted. Each year since planting ages the tree one year.

Some trees may be planted before or after reaching the standard planting size. The effective number of trees is adjusted according to survival rate. For example, a species that is planted at a smaller-than-usual size can require two years to reach age 0. In those two years, not all trees will survive. Thus, the effective number of trees planted is adjusted by this survival rate. This effective number of trees is then used in the calculation, and the year that they reach age 0 still remains as age 0. The survival rates used for these planting adjustments are in Table A- 3 for hardwoods and Table A- 4 for conifers.

For example, 100 blue spruce trees might be planted at an age of -1 in 2008. As the survival factor for a moderate-growth rate conifer is .873, we estimate that 87.3 trees survived to 2009. Thus, in 2009, when the trees hit age 0, the effective number of trees planted at age 0 is 87.3. In 2010, the trees are 1 year old.

This methodology can be adapted into a spreadsheet tool in order to estimate the sequestration by a set of trees over their lifetime. Thus, an agency planning an urban park can enter the species, age, and number of trees to be planted, and the spreadsheet will provide an estimate of the sequestration by the whole set.

An alternative approach would be to adopt the methodology used by researchers for existing urban trees. The CCAR/FS methodology, which was adapted from the UNFCCC methodology, utilizes field measurements to estimate biomass and, in turn, carbon stock. The stock can be compared from one year to the next to arrive at a sequestration value.

This methodology would require the use of tree growth projections in order to use it for planned parks. Effectively, a predicted tree height and diameter could be used in place of field observations, and carbon stocks for all future years could be calculated. This process could be streamlined with the uses of the CCTC tool that estimates carbon stocks given tree parameters.

Both approaches present limitations in accuracy, as a result of the assumptions they use. The Department of Energy approach groups trees into broad categories for the purpose of modeling sequestration over their lifetimes; clearly, the hundreds of tree species used in North American urban parks have more variation than six groups can capture. Nonetheless, by use of this approach, the growth of trees can be modeled over decades, accounting for survival rates.

On the other hand, the methodology that depends on field measurements can be very accurate and species-specific if the growth estimates are accurate and species-specific. For example, developing a growth model for each of the species to be planted in a new park will make this methodology more specific than one that groups species into broad categories. Any growth model should, of course, take survival factors into account.

4.3 Energy Reductions Due to Park Trees

"Heat islands" refer to urban areas where the air and surface temperatures are greater than in nearby rural areas. Most cities today exhibit some degree of heat island effects, which are exacerbated by the loss of vegetation and the increase in low albedo surfaces. Low albedo surfaces, which include dark paving and roofing materials, absorb more solar radiation than high albedo surfaces like undeveloped land and lighter colored roofing materials (Gray and Finster). Such heat islands lead to increased energy consumption by requiring increased air conditioning and cooling. It is estimated that for cities with populations of over 100,000 people, ever 1° F increase in temperature leads to a 1.5 to 2 percent increase in peak utility loads (Ibid.).

The trees and vegetation provided by urban parks provide an effective way to reduce urban heat islands. On an individual level, carefully selected and planted trees can reduce the energy consumption for individual buildings. Trees achieve this effect by providing shade and evapotranspiration to cool buildings during summer, thereby reducing the need to run air conditioners and consume electricity (EPA, 2007). Lawrence Berkeley National Laboratory researchers demonstrated that trees and other heat island reduction measures can combine to reduce building carbon emissions by 5-20 percent (Akbari and Konopacki, 2003).

The calculations to estimate these benefits are rather sophisticated, depending on latitude, local climate, distance from building, tree size and species, and other factors. A variety of online tools exist to facilitate these calculations. These include the "Tree Benefit Estimator" developed by the American Public Power Association and the Sacramento Municipal Utility District (SMUD), the CUFR's i-Tree software tools. Because these methods rely on a variety of highly site-specific factors and existing tools have been well-established, it is recommended that users take advantage of these resources to estimate GHG benefits in this area.

4.4 Challenges and Uncertainties

Both the carbon sequestration and energy reduction benefits of urban trees have high degrees of uncertainty associated with them. The CCAR methodology discussed above, which relies on direct measurement of a sample of trees and sophisticated calculations, is sufficiently robust for GHG accounting efforts under the CCAR. The DOE methodology for planned parks presents a much higher level of uncertainty due to the broad categories of tree growth rates and the assumptions about tree sequestration rates and mortality. Local factors such as soil quality, rainfall, and tree care may slow down or speed up carbon sequestration. Due to these variations, the DOE methodology is only recommended for estimates where direct measurement is not possible and a high level of precision is not required.

5 Conclusion

In addition to the social benefits that are seen with the addition of green space, such as opportunities for educating the public about nature and environmental issues, promoting community revitalization, providing a hub for economic development and increasing property values, urban parks help reduce emissions indirectly by contributing to the quality of life in dense, carbon-efficient urban neighborhoods and directly through the methods outlined throughout the paper. The air quality, water quality, recreational, and other social benefits parks provide have long been known, but as governments develop a comprehensive response to climate change, increasing attention will be paid to the role parks

play in reducing GHG emissions. The methods outlined here—particularly in the areas of transportation and groundwater recharge—can be used to develop tools to help planners estimate the carbon benefits from urban parks. These can be used in conjunction with existing carbon sequestration estimators and heat island reduction calculators to develop a broader picture of the reductions that can be realized by increasing the availability and distribution of urban parks. Although these methodologies do present some uncertainty, knowledge of parks' GHG benefits provides planners with yet another powerful argument for increasing public and private investment in parks. With the successful introduction of more urban parks, communities can improve the quality of life for their residents while taking concrete steps toward reducing their GHG emissions.

References

Akbari, H. and Konopacki, S. 2003. "Streamlined energy-savings calculations for heat-island reduction strategies." Lawrence Berkeley National Laboratory: Berkeley, CA. LBNL Paper #47307.

Allen, E. and F. Benfield, 2005. "Environmental Characteristics of Smart Growth Neighborhoods: Phase II: Two Nashville Neighborhoods." National Resources Defense Fund. www.nrdc.org/cities/smartgrowth/char/charnash.pdf

Anderson, J. 2003. *The environmental benefits of water recycling and reuse.* Water Science and Technology: Water Supply, Vol. 3, No. 4, pg. 1-10.

ARPPS (American River Parkway Preservation Society. Online, accessed August 20, 2008. www.arpps.org/

CARB (California Air Resources Board). 2005. *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects.* Published May 2005. http://www.arb.ca.gov/planning/tsaq/eval/mv_fees_cost-effectiveness_methods_may05.doc

CCAR (California Climate Action Registry). 2008. "General Reporting Protocol: Reporting Entity-Wide Greenhouse Gas Emissions, Version 3.0." April, 2008.

CCAR (California Climate Action Registry). 2008a. "Urban Forest Greenhouse Gas Reporting Protocol." June 1, 2008.

CCI (Community Conservancy International). 2008. *The green solution project: creating and restoring park, habitat, recreation and open space on public lands to naturally clean polluted urban and stormwater runoff.* Published March 2008.

CEC (California Energy Commission). 2006a. *Inventory of California greenhouse gas emissions and sinks: 1990-2004.* Published December 2006.

CEC (California Energy Commission). 2006b. *Water supply related electricity demand in California.* Published December 2006.

CEC (California Energy Commission). Online, accessed July 1, 2008. *Water energy use in California.* energy.ca.gov/pier/iaw/industry/water.html

Chralowicz, D., A. Dominguez, T. Goff, M. Mascali, and E. Taylor. 2001. *Infiltration of urban stormwater runoff to recharge groundwater used for drinking water: A study of the San Fernando Valley, California.* A group project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management, University of California, Santa Barbara.

City of Los Angeles. 2008. *Securing L.A.'s water supply: City of Los Angeles Water supply Action Plan.* Published May, 2008. www.ladwp.com/ladwp/cms/ladwp010587.pdf

Cohen, Deborah; Sehgal, Amber; Williamson, Stephanie; Sturm, Roland; McKenzie, Thomas L.; Lara, Rosa; and Lurie, Nicole. 2006. "Park Use and Physical Activity in a Sample of Public Parks in the City of Los Angeles." Published 2006 by the RAND Corporation.

Correll, Mark R., Jane H. Lillydahl, and Larry D. Singell. 1978. "The Effects of Greenbelts on Residential Property Values: Some Findings on the Political Economy of Open Space." Land Economics 54(2): 207–17.

Design Center for American Urban Landscape (DCAUL). 2003. *The diversity of green spaces.* College of Architecture and Landscape Architecture, University of Minnesota.

Dunse, N., C. Dehring, and M. White. 2007. *Urban parks, open space, and residential property value.* Findings

in Built and Rural Environments (FiBRE), Rural Institution of Chartered Surveyors. United Kingdom. Publish July 2007.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. *Stream Corridor Restoration: Principles, Processes, and Practices*. (FISRWG)(15 Federal agencies of the US government). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN3/PT.653. ISBN-0-934213-59-3.

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., and Chen, D. 2008. *Growing Cooler: The Evidence on Urban Development and Climate Change*. Washington, DC: Urban Land Institute.

Gray, K. A., Finster, M. E. "The Urban Heat Island, Photochemical Smog, and Chicago: Local Features of the Problem and Solution." Evanston, IL: Northwestern University.

Groisman P., R. Knight, D. Easterling, T. Karl, G. Hegerl, V. Razuvaev. 2005. Trends in Intense Precipitation in the Climate Record. Journal of Climate 18:1326-1350.

Hammer, Thomas R., Robert E. Coughlin, and Edward T. Horn IV. 1974. "The Effect of a Large Urban Park on Real Estate Value." *American Institute of Planning Journal* July: 274–77.

Harnik, P. and Simms, J. 2004. Parks: How far is too far? American Planning Association. Accessed online in March 20, 2006 at www.tpl.org/content_documents/cityparks_Planning_mag_article12 2004.pdf.

ICF International, 2006. "Transportation Fund for Clean Air Program Evaluation. Final Report." Prepared for the Bay Area Air Quality Management District.

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Kramer, L. and J. Dorfman. 2000. *A toolkit for the evaluation of land parcels for green space planning*. University of Georgia River Basin Center.

Leon Younger & PROS, 2004. "Fairfax County Needs Assessment Final Report." Presented to the Fairfax County Park Authority.

Lindsey, G., 1999. Use of urban greenways: insights from Indianapolis. J. Landscape. Urban Plan. 594, 1–13.

Lindsey, G., Nguyen, D., 2004. Use of greenway trails in Indiana. J. Urban Plan. Dev. 130 (4), 213–217.

Lindsey, Wilson, Rubchinskayaa, Yang and Han. 2007. "Estimating urban trail traffic: Methods for existing and proposed trails." *Landscape and Urban Planning*. 81(4), 299-315.

Long Beach Water Department (LBWD). 2006. Press Release: *Per capita water use in Long beach reduced 12% since 2000*. November 2, 2006. www.lbwater.org/pdf/PressReleases/11-02-06PR.pdf

Mill River Collaborative. 2008. Master Plan: Virtaul Tour. Accessed online August 4, 2008. www.millriver.info/virtual_tour.htm

Moore, R., Graffe, A., Gitelson, R., Portert, B., 1992. The Impacts of Rail-Trails. A Study of User and Property Owners from Three Trails. National Park Service, Washington, DC, on National Park Service Parknet: www.cr.nps.gov/rtca/rtc/impact-f.htm.

Morris, Hugh. 2002. "Trails & Greenways: Advancing the Smart Growth Agenda." Prepared for the Rails to Trails Conservancy.

National Governor's Association. 2000. "In the Fast Lane: Delivering more Transportation Choices to Break Gridlock." National Governor's Association. Washington, D.C.

Natural Resources Defense Council (NRDC). 2000. "Environmental Characteristics of Smart Growth Neighborhoods: An Exploratory Case Study." National Resources Defense Fund. www.nrdc.org/cities/smartGrowth/char/exesum.asp

Natural Resources Defense Council (NRDC). 2004. *Energy down the drain: the hidden costs of California's water supply*. Oakland, California. www.nrdc.org/water/conservation/edrain/edrain.pdf

Nelson, A.C. and D. Allen. 1997. "If You Build Them, Commuters Will Use Them: Association Between Bicycle Facilities and Bicycle Commuting." T*ransportation Research Record*. Transportation Research Board. Washington, D.C.

Noland, Robert B. and Lewinson, L. Lem. 2000. "Induced Travel: A Review of Recent Literature and the Implications for Transportation and Environmental Policy".

PFK Consulting, 1994. Analysis of Economic Impacts of the Northern Central Rail Trail.

Rimpo and Associates. Urbemis Model. 2007. Available at: www.urbemis.com

San Diego Municipal Code. Land Development Code. Trip Generation Manual. Revised May 2003

Sister, C., Wolch, J., Wilson, J., Seymour, M., Linder, A., Byrne, J. and Swift, J. 2007. Parks and Open Space Resources in the Green Visions Plan Area. University of Southern California Center for Sustainable Cities and GIS Research Laboratory, Los Angeles, CA.

Talen, E. 1998. Visualizing fairness: Equity maps for planners. Journal of the American Planning Association 64: 22-39.

The River Project, 2006. State of the Tujunga report. Published October 2006.

TreePeople. 2007. Rainwater as a resource. Beverly Hills, CA. www.treepeople.org/files/Rainwater_as_a_Resource.pdf

TreePeople. Accessed online July 8, 2008. *Design Charrette: Planbook Introduction*. www.treepeople.org/trees/PBintro.htm

UNFCCC (United Nations Framework Convention on Climate Change). 2007. "Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the CDM implemented on settlements." AR-AMS0002. Dec. 14, 2007.

U.S. Department of Agriculture (USDA). 1986. *Urban hydrology for small watersheds*. Technical Release 55. Released June, 1986.

U.S. Department of Agriculture (USDA). 2007. National Engineering Handbook, Part 630: Hydrology. Chapter 7: *Hydrologic soil groups*.

U.S. Department of Energy. 1998. "Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings." Energy Information Administration, U.S. Department of Energy. Available online at: ftp://ftp.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/sequester.pdf.

U.S. Department of Transportation (USDOT). 2006. *National Transportation Statistics*. Available online at: www.bts.gov/publications/national_transportation_statistics.

U.S. Environmental Protection Agency. 2007. "Heat Island Effect". www.epa.gov/heatisland/strategies/index.html

U.S. Environmental Protection Agency. 2008. *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2006*. Washington, DC.

U.S. Environmental Protection Agency. Accessed online July 8, 2008. Emissions & Generation Resource Integrated Database (eGRID). www.epa.gov/solar/energy-resources/egrid/

Winrock International. 2004. "Carbon Supply from Changes in Management of Forest, Range, and Agricultural Lands of California." Prepared for the California Energy Commission, Public Interest Energy Research Program.

Wolff, G. 2005. *Quantifying the Potential Air Quality Impacts from Electric Demand Embedded in Water Management Choices*. The Pacific Institute for the California Energy Commission, PIER Energy-Related Environmental Research. CEC-500- 2005-031.

Appendix A: Carbon Sequestration in Trees

Table A-1: Growth Rate and Type for Urban Tree Species

Type: H=Hardwood, C=Conifer **Growth**: F=Fast, M=Medium, S=Slow

Tree Species	Type	Growth
Ailanthus, *Ailanthus altissima*	H	F
Alder, European, *Alnus glutinosa*	H	F
Ash, green, *Fraxinus pennsylvanica*	H	F
Ash, mountain, *American,Sorbus americana*	H	M
Ash, white, *Fraxinus americana*	H	F
Aspen, bigtooth, *Populus grandidentata*	H	M
Aspen, quaking, *Populus tremuloides*	H	F
Baldcypress, *Taxodium distichum*	C	F
Basswood, *American, Tilia americana*	H	F
Beech, American, *Fagus grandifolia*	H	S
Birch, paper (white), *Betula papyrifera*	H	M
Birch, river, *Betula nigra*	H	M
Birch, yellow, *Betula alleghaniensis*	H	S
Boxelder, *Acer negundo*	H	F
Buckeye, Ohio, *Aesculus glabra*	H	S
Catalpa, northern, *Catalpa speciosa*	H	F
Cedar-red, eastern, *Juniperus virginiana*	C	M
Cedar-white, northern, *Thuja occidentalis*	C	M
Cherry, black, *Prunus serotina*	H	F
Cherry, pin, *Prunus pennsylvanica*	H	M
Cottonwood, eastern, *Populus deltoides*	H	M
Crabapple, *Malusspp*	H	M
Cucumbertree, *Magnolia acuminata*	H	F
Dogwood, flowering, *Cornus florida*	H	S
Elm, American, *Ulmus americana*	H	F
Elm, Chinese, *Ulmus parvifolia*	H	M
Elm, rock, *Ulmus thomasii*	H	S
Elm, September, *Ulmus serotina*	H	F
Elm, Siberian, *Ulmus pumila*	H	F
Elm, slippery, *Ulmus rubra*	H	M
Fir, balsam, *Abies balsamea*	C	S
Fir, Douglas, *Pseudotsuga menziesii*	C	F
Ginkgo, *Ginkgo biloba*	H	S
Hackberry, *Celtis occidentalis*	H	F
Hawthorne, *Crataegusspp*	H	M

	Type: H=Hardwood, C=Conifer	**Growth**: F=Fast, M=Medium, S=Slow
Hemlock, eastern, *Tsuga canadensis*	C	M
Hickory, bitternut, *Carya cordiformis*	H	S
Hickory, mockernut, *Carya tomentosa*	H	M
Hickory, shagbark, *Carya ovata*	H	S
Hickory, shellbark, *Carya laciniosa*	H	S
Hickory, pignut, *Carya glabra*	H	M
Holly, American, *Ilex opaca*	H	S
Honeylocust, *Gleditsia triacanthos*	H	F
Hophornbeam, eastern, *Ostrya virginiana*	H	S
Horsechestnut, common, *Aesculus hippocastanum*	H	F
Kentucky coffeetree, *Gymnocladus dioicus*	C	F
Linden, little-leaf, *Tilia cordata*	H	F
Locust, black, *Robinia pseudoacacia*	H	F
London plane tree, *Platanus_X_acerifolia*	H	F
Magnolia, southern, *Magnolia grandifolia*	H	M
Maple, bigleaf, *Acer macrophyllum*	H	S
Maple, Norway, *Acer platanoides*	H	M
Maple, red, *Acer rubrum*	H	M
Maple, silver, *Acer saccharinum*	H	M
Maple, sugar, *Acer saccharum*	H	S
Mulberry, red, *Morus rubra*	H	F
Oak, black, *Quercus velutina*	H	M
Oak, blue, *Quercus douglasii*	H	M
Oak, bur, *Quercus macrocarpa*	H	S
Oak, California black, *Quercus kelloggii*	H	S
Oak, California White, *Quercus lobata*	H	M
Oak, canyon live, *Quercus chrysolepsis*	H	S
Oak, chestnut, *Quercus prinus*	H	S
Oak, Chinkapin, *Quercus muehlenbergii*	H	M
Oak, Laurel, *Quercus laurifolia*	H	F
Oak, live, *Quercus virginiana*	H	F
Oak, northern red, *Quercus rubra*	H	F
Oak, overcup , *Quercus lyrata*	H	S
Oak, pin, *Quercus palustris*	H	F
Oak, scarlet, *Quercus coccinea*	H	F
Oak, swamp white, *Quercus bicolor*	H	M
Oak, water, *Quercus nigra*	H	M
Oak, white, *Quercus alba*	H	S
Oak, willow, *Quercus phellos*	H	M

	Type: H=Hardwood, C=Conifer	**Growth**: F=Fast, M=Medium, S=Slow
Pecan, *Carya illinoensis*	H	S
Pine, European black, *Pinus nigra*	C	S
Pine, jack, *Pinus banksiana*	C	F
Pine, loblolly, *Pinus taeda*	C	F
Pine, longleaf, *Pinus palustris*	C	F
Pine, ponderosa, *Pinus ponderosa*	C	F
Pine, red, *Pinus resinosa*	C	F
Pine, Scotch, *Pinus sylvestris*	C	S
Pine, shortleaf, *Pinus echinata*	C	F
Pine, slash, *Pinus elliottii*	C	F
Pine, Virginia, *Pinus virginiana*	C	M
Pine, white eastern, *Pinus strobus*	C	F
Poplar, yellow, *Liriodendron tulipifera*	H	F
Redbud, eastern, *Cercis canadensis*	H	M
Sassafras, *Sassafras albidum*	H	M
Spruce, black, *Picea mariana*	C	S
Spruce, blue, *Picea pungens*	C	M
Spruce, Norway, *Picea abies*	C	M
Spruce, red, *Picea rubens*	C	S
Spruce, white, *Picea glauca*	C	M
Sugarberry, *Celtis laevigata*	H	F
Sweetgum, *Liquidambar styraciflua*	H	F
Sycamore, *Platanus occidentalis*	H	F
Tamarack, *Larix laricina*	C	F
Walnut, black, *Juglans nigra*	H	F
Willow, black, *Salix nigra*	H	F

Source: DOE, 1998.

Table A-2: C Sequestration Rates and Survival Factors for Tree Types and Growth Rates

Tree Age (yrs)	Survival Factors by Growth Rate			Annual Sequestration Rates by Tree Type and Growth Rate (lbs. carbon/tree/year)					
				Hardwood			Conifer		
	Slow	Moderate	Fast	Slow	Moderate	Fast	Slow	Moderate	Fast
0	0.873	0.873	0.873	1.3	1.9	2.7	0.7	1	1.4
1	0.798	0.798	0.798	1.6	2.7	4	0.9	1.5	2.2
2	0.736	0.736	0.736	2	3.5	5.4	1.1	2	3.1
3	0.706	0.706	0.706	2.4	4.3	6.9	1.4	2.5	4.1
4	0.678	0.678	0.678	2.8	5.2	8.5	1.6	3.1	5.2
5	0.658	0.658	0.658	3.2	6.1	10.1	1.9	3.7	6.4
6	0.639	0.639	0.644	3.7	7.1	11.8	2.2	4.4	7.6
7	0.621	0.621	0.63	4.1	8.1	13.6	2.5	5.1	8.9
8	0.603	0.603	0.616	4.6	9.1	15.5	2.8	5.8	10.2
9	0.585	0.589	0.602	5	10.2	17.4	3.1	6.6	11.7
10	0.568	0.576	0.589	5.5	11.2	19.3	3.5	7.4	13.2
11	0.552	0.564	0.576	6	12.3	21.3	3.8	8.2	14.7
12	0.536	0.551	0.563	6.5	13.5	23.3	4.2	9.1	16.3
13	0.524	0.539	0.551	7	14.6	25.4	4.6	9.9	17.9
14	0.512	0.527	0.539	7.5	15.8	27.5	4.9	10.8	19.6
15	0.501	0.516	0.527	8.1	16.9	29.7	5.3	11.8	21.4
16	0.49	0.504	0.516	8.6	18.1	31.9	5.7	12.7	23.2
17	0.479	0.493	0.505	9.1	19.4	34.1	6.1	13.7	25
18	0.469	0.483	0.495	9.7	20.6	36.3	6.6	14.7	26.9
19	0.459	0.472	0.484	10.2	21.9	38.6	7	15.7	28.8
20	0.448	0.462	0.474	10.8	23.2	41	7.4	16.7	30.8
21	0.439	0.452	0.464	11.4	24.4	43.3	7.9	17.8	32.8
22	0.429	0.442	0.454	12	25.8	45.7	8.3	18.9	34.9
23	0.419	0.433	0.445	12.5	27.1	48.1	8.8	20	37
24	0.41	0.424	0.435	13.1	28.4	50.6	9.2	21.1	39.1
25	0.401	0.415	0.426	13.7	29.8	53.1	9.7	22.2	41.3
26	0.392	0.406	0.417	14.3	31.2	55.6	10.2	23.4	43.5
27	0.384	0.398	0.409	15	32.5	58.1	10.7	24.6	45.7
28	0.375	0.389	0.4	15.6	33.9	60.7	11.2	25.8	48
29	0.367	0.381	0.392	16.2	35.3	63.3	11.7	27	50.3
30	0.359	0.373	0.383	16.8	36.8	65.9	12.2	28.2	52.7
31	0.352	0.365	0.375	17.5	38.2	68.5	12.7	29.5	55.1
32	0.344	0.358	0.367	18.1	39.7	71.2	13.3	30.7	57.5
33	0.337	0.35	0.36	18.7	41.1	73.8	13.8	32	59.9
34	0.33	0.343	0.349	19.4	42.6	76.5	14.3	33.3	62.4
35	0.323	0.336	0.339	20	44.1	79.3	14.9	34.7	64.9
36	0.316	0.329	0.329	20.7	45.6	82	15.5	36	67.5
37	0.31	0.322	0.32	21.4	47.1	84.8	16	37.3	70.1
38	0.303	0.315	0.31	22	48.6	87.6	16.6	38.7	72.7
39	0.297	0.308	0.301	22.7	50.2	90.4	17.2	40.1	75.3
40	0.291	0.302	0.293	23.4	51.7	93.2	17.7	41.5	78
41	0.285	0.296	0.284	24.1	53.3	96.1	18.3	42.9	80.7
42	0.279	0.289	0.276	24.8	54.8	99	18.9	44.3	83.4
43	0.273	0.283	0.268	25.4	56.4	101.9	19.5	45.8	86.2
44	0.267	0.277	0.26	26.1	58	104.8	20.1	47.2	89
45	0.261	0.269	0.253	26.8	59.6	107.7	20.7	48.7	91.8
46	0.256	0.261	0.245	27.6	61.2	110.7	21.3	50.2	94.7
47	0.251	0.254	0.238	28.3	62.8	113.6	22	51.7	97.5
48	0.245	0.247	0.231	29	64.5	116.6	22.6	53.2	100.4
49	0.24	0.239	0.225	29.7	66.1	119.6	23.2	54.8	103.4
50	0.235	0.232	0.218	30.4	67.8	122.7	23.9	56.3	106.3
51	0.23	0.226	0.212	31.1	69.4	125.7	24.5	57.9	109.3
52	0.225	0.219	0.206	31.9	71.1	128.8	25.2	59.4	112.3
53	0.221	0.213	0.199	32.6	72.8	131.8	25.8	61	115.4
54	0.216	0.207	0.193	33.4	74.5	134.9	26.5	62.6	118.4
55	0.211	0.201	0.188	34.1	76.2	138	27.2	64.2	121.5
56	0.207	0.195	0.182	34.8	77.9	141.2	27.8	65.9	124.6
57	0.203	0.189	0.177	35.6	79.6	144.3	28.5	67.5	127.8
58	0.198	0.184	0.171	36.3	81.3	147.5	29.2	69.2	130.9
59	0.194	0.178	0.166	37.1	83	150.6	29.9	70.8	134.1

Source: DOE, 1998.

Table A-3: Adjustment for Hardwoods Planted at Non-standard Size(DWP)

Size of Tree When Planted	Tree Age	Survival Factor
Bare Root Seedling	-6	0.443
10 Gallon Container	-2	0.762
15 Gallon Container	0	1
Balled and Burlapped	0	1

Source: DOE, 1998.

Table A-4: Adjustment for Conifers Planted at Nonstandard Size

Growth Rate	Tree Height in Feet	Tree Age	Survival Factor
Slow	Less than 1	-6	0.443
	1 - 2	-5	0.507
	2 - 3	-4	0.581
	3 - 4	-3	0.665
	4 - 5	-2	0.762
	5 - 6	-1	0.873
	6 - 7	0	1
	7 - 8	1	1.145
	8 - 9	2	1.253
	9 - 10	3	1.416
	10 - 11	4	1.475
Moderate	1.6 or less	-4	0.581
	1.6 - 3.2	-3	0.665
	3.2 - 4.8	-2	0.762
	4.8 - 6.4	-1	0.873
	6.4 - 8.2	0	1
	8.2 - 9.8	1	1.145
	9.8 - 11.4	2	1.253
	11.4 - 13.0	3	1.416
	13.0 - 14.6	4	1.475
Fast	Less than 2.3	-3	0.665
	2.3 - 4.6	-2	0.762
	4.6 - 6.9	-1	0.873
	6.9 - 9.2	0	1
	9.2 - 11.5	1	1.145
	11.5 - 13.8	2	1.253
	13.8 - 16.1	3	1.416
	16.1 - 18.4	4	1.475

Source: DOE, 1998.