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The Tree Project:

Integrated Urban Environmental Improvement Through Tree Selection and Management

Phase 1 Report

January 2007

APPENDIX B
Technical Tutorials
Urban Forest Environmental Services and Impacts

The Tree Project: Phase 1 Report

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Technical Tutorials

Urban Forest Environmental Services and Impacts

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Introduction

The trees of the urban forest are different from their naturally occurring counterparts, because they are the framework for green infrastructure, and must be managed, maintained, and evaluated like any other structural component of the city. Trees in urban areas can function as water filtration systems, and energy and water conservation devices. They can also reduce outdoor temperatures, improve air quality, and mitigate gases in the atmosphere that contribute to global climate change. However, like other elements of urban infrastructure, without proper care, selection, and placement, trees may also cause environmental costs, such as increased atmospheric ozone levels and a depleted water supply in areas with already limited sources. The following tutorials are brief reviews of the scientific impacts of trees on global climate change, carbon sequestration, air quality, energy consumption, water quality, and water supply.

Trees Impact Global Climate Change

Atmospheric Greenhouse Effect/Global Warming

The greenhouse effect is a natural process that makes life on Earth possible. Sunlight passes through the atmosphere, warming the Earth's surface. In turn, the land and oceans release heat, or infrared radiation, back into the atmosphere, balancing the incoming energy (see Figure 1). The type of surface that sunlight first encounters is the most important factor in the atmospheric greenhouse effect. Forests, grasslands, ocean surfaces, ice caps, deserts, and cities all absorb, reflect, and emit radiation differently. Sunlight falling on a white glacier surface mainly reflects back into space, resulting in minimal heating of the surface and lower atmosphere. Sunlight falling on dark surfaces such as desert soil or blacktop is mostly absorbed, on the other hand, and contributes to significant heating of the surface of the earth and lower atmosphere. Cloud cover can also affect this greenhouse-like warming of the earth by both reducing the amount of solar radiation reaching the earth's surface and by reducing the amount of radiant energy emitted into space.

Atmospheric greenhouse gases (water vapor, carbon dioxide, and other naturally occurring gases) trap some of the outgoing energy, retaining heat somewhat like the glass panels of a greenhouse. Without this naturally retained heat, temperatures on Earth would be much lower, and life as it is today would not be possible. However, problems arise when the atmospheric concentration of these greenhouse gases increases (CSIRO, n.d.).

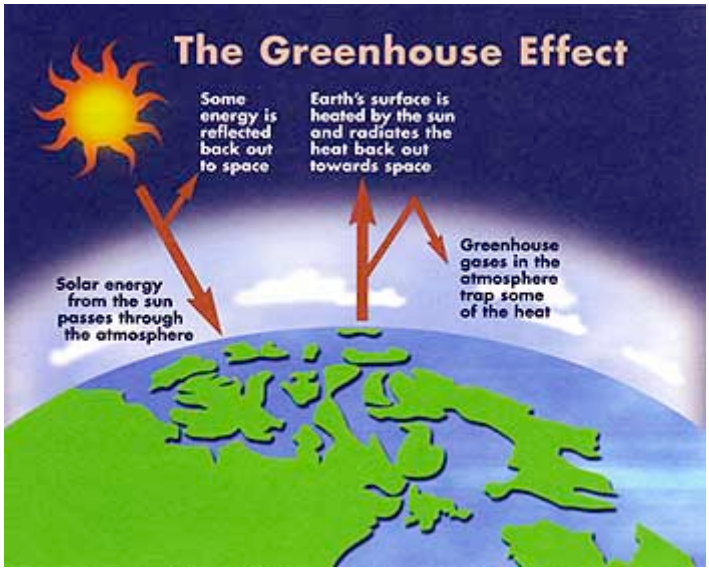


Figure 1

Some greenhouse gases occur naturally in the atmosphere, but can be enhanced by human activity, and some are solely the result of human activity. Naturally occurring gases include water vapor, methane, nitrous oxide, ozone, and carbon dioxide. Each greenhouse gas differs in its ability to absorb heat in the atmosphere, having a distinct impact on the greenhouse effect, or global warming. Some gases that are not naturally occurring are very powerful, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), which are generated in a variety of industrial processes (EPA, 2000). HFCs, for example are used in refrigeration, in air-conditioning, and also in foam blowing agents, solvents, fire-fighting agents and aerosols. HFCs make up only a small portion of total greenhouse gas emissions, but depending on type, they can be up to 20,000 times more potent than the most prevalent greenhouse gas - carbon dioxide - and can remain in the atmosphere for up to 260 years (Greenpeace International, n.d.)

Methane

Methane (CH_4) is emitted naturally in anaerobic conditions (places where oxygen is limited) from bogs, wetlands, landfills, rice paddies, termites, vegetation fires, and decomposing organic matter (CSIRO, 2006). In addition, a recent study by Frank Keppler of the Max Planck Institute has indicated that plants may emit methane directly. However, more research needs to be done to discover the significance of this finding to global warming (Hirsch, 2006). Methane is also emitted during the production and transport of coal, natural gas, and oil, and in raising livestock.

The greenhouse gas methane remains in the atmosphere for 9 to15 years and is over 20 times more effective in trapping heat in the atmosphere than is carbon dioxide. However, the concentration of carbon dioxide in the atmosphere is much higher, and therefore contributes significantly to global warming.

Carbon Dioxide (CO_2)

Carbon Dioxide (CO_2) is a nontoxic gas that occurs both naturally in the atmosphere (e.g. volcanic emissions, organism respiration, and decaying tree matter), and as a result of man-made sources (e.g. burning oil, coal, and natural gas for energy). Scientists believe that the earth's production and consumption of CO_2 was in balance prior to the industrial revolution. However, through industrial processes over the last century, humans have been releasing this greenhouse gas into the atmosphere much faster than natural processes can remove it. Trees, particularly urban trees, provide a natural way to mitigate the increase in atmospheric carbon due to global growth both directly, by acting as a "carbon sink," and indirectly, by reducing the demand for energy by providing shade.

Carbon Sequestration and Urban Forests

Trees remove carbon dioxide from the air both directly and indirectly. As trees "breathe," they directly absorb carbon dioxide and release oxygen through their leaves. Through the process of photosynthesis, trees remove the carbon from the CO_2 (CO_2 = 1 carbon atom and 2 oxygen atoms) and store it as cellulose in their biomass (i.e. trunk, leaves, stems, roots, and branches), while releasing the oxygen back into the air. The amount of carbon absorbed annually varies by as much as 35 to 800 lbs. depending on tree growth rate, age, and size. In general, a mature tree may absorb 1,000 times more carbon than do small, young trees (EPA, 2005). Urban forests play an important role in atmospheric carbon levels and should not be overlooked as a valuable tool in reducing these levels. In fact, the U.S. Forest Service estimates that carbon storage in urban forests' aboveground biomass is between 400 and 900 million metric tons nationally (Nowak, 1994 as cited in City of Boulder, 2002).

A large portion of sequestered carbon is stored in the trees' aboveground biomass system; however, the belowground root system actually offers great potential for mitigating atmospheric carbon levels. The combination of porous soil and the extensive root system below a mature tree stores more carbon than tree trunk, stems, leaves, and branches combined. Most of the carbon stored in soil comes from decaying organic matter such as leaves or other dead plant biomass.

Although trees generally provide for an overall net decrease in atmospheric carbon, they also contribute to the release of carbon back into the atmosphere: burning wood leads to large amounts of released CO_2, dead or dying trees naturally emit carbon as they decay, and tree maintenance calls for the use of CO_2 - releasing machinery such as chippers, chain saws, and vehicle emissions (Brown, 2000). Figures 2 and 3 illustrate these complex relationships.

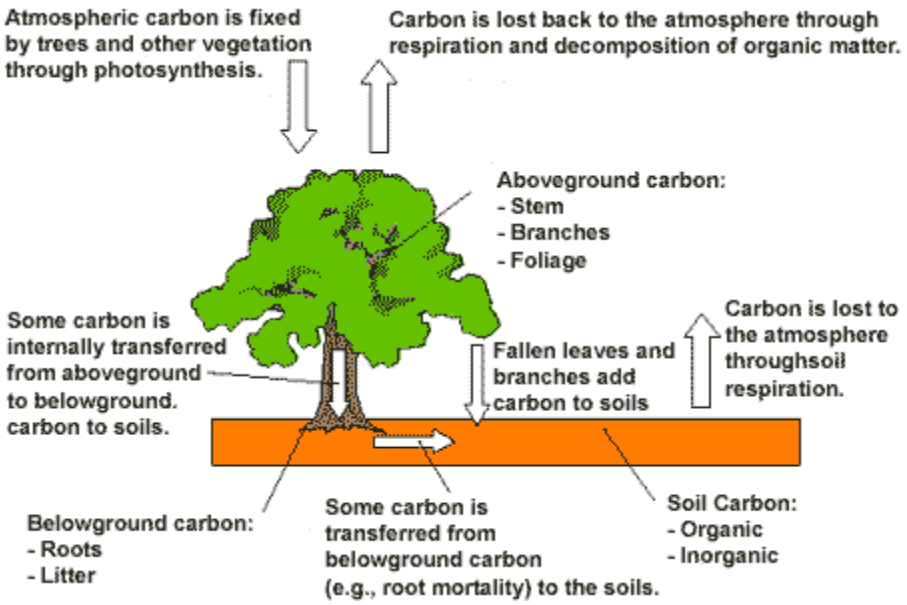


Figure 2

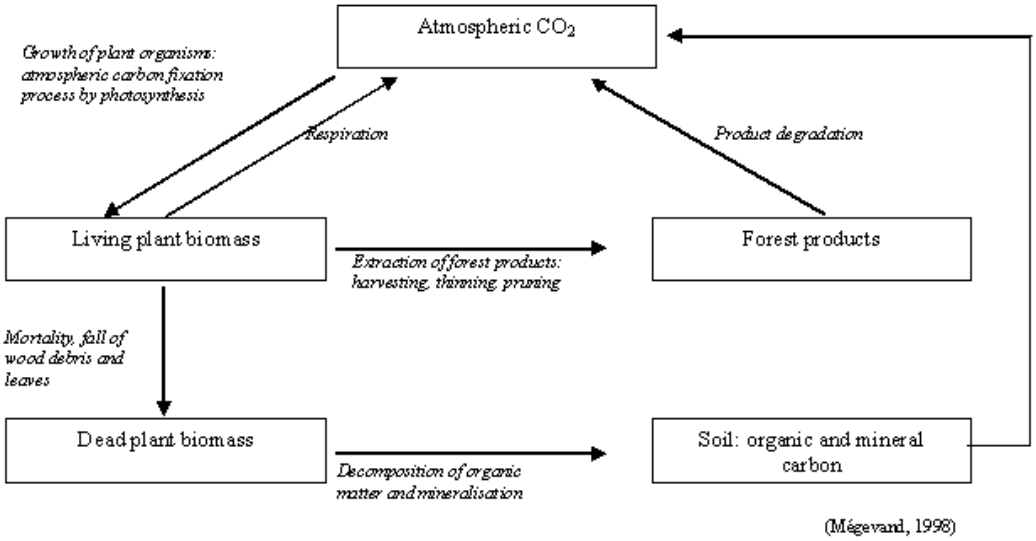


Figure 3

CO_2 Emissions Reduction

Trees also indirectly reduce atmospheric carbon levels by providing shade, which leads to avoided power plant emissions of carbon dioxide. Trees are actually more beneficial in providing for avoided power plant emissions than in direct carbon sequestration (City of Boulder, 2002). Trees reduce the atmospheric greenhouse effect by preventing CO_2 emissions from power plants by reducing demand for energy, and by cooling the air through the transpiration process. By shading homes and office buildings, trees indirectly reduce the need for air conditioning and power generation. Because energy production is a major source of carbon emissions, urban trees

are responsible for preventing more carbon from being released than they can remove from the air through sequestration (City of Boulder, 2002). The amount of impact trees can have on energy reduction depends on proper placement of trees, proper species selection, age, and height.

Through the process of transpiration, trees draw water from the soil into their roots and release water through the leaf stomata, which then mixes with the heat from the air to form water vapor, cooling and adding humidity to the air. This reduction in ambient air temperature leads to decreased use of air conditioning in cars and in buildings, which lowers CO_2 emissions significantly (see Figure 4).

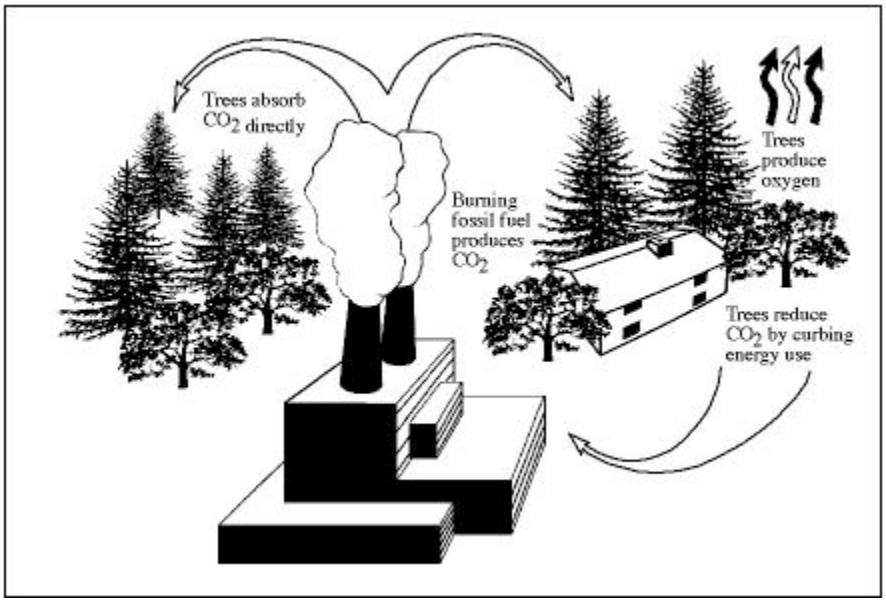


Figure 4

Calculating Carbon Storage

Trees store carbon both above and belowground in their biomass. Though the amount of carbon stored belowground in root systems is more difficult to estimate, in general, the amount of carbon stored in each tree is calculated through the following process. First, the volume of the tree is calculated using tree height and diameter. The tree volume is then converted to tons of dry wood. The weight of dry wood is then divided into the weight of carbon and the weight of other elements that make up tree biomass, such as hydrogen and oxygen. For example, "a fast growing eucalypt planted forest averaging a stem growth rate of 20 cubic meters of wood per hectare per year may yield 500 kg of dry wood per cubic meter. This will generate 10 tons of dry wood per hectare per year, of which 5 tons (50 percent) will be carbon." (NSW, 2005)

Trees Impact Air Quality

Colorado Air Quality and Urban Forests

"Colorado's Front Range has a long-standing problem with air quality." (City of Boulder, 2002) In the late 1970s, Denver violated the federal air quality standard for five of the six regulated air pollutants (carbon monoxide, lead, nitrogen oxides, ground-level ozone, and particulate matter, excluding sulfur dioxide) more than 200 days a year, making it a designated "non-attainment" area by the Environmental Protection Agency (Svoboda et al., 2002). Although the region has improved air quality significantly through voluntary air cleanup efforts for the last 30 years, over 200,000 people in Boulder County alone face a cancer risk more than 100 times the goal set by the Clean Air Act due to high levels of air pollution (City of Boulder, 2002).

The air quality problem along the Front Range of Colorado is fundamentally regional in nature. In the 1980s, Denver was infamous for the "Brown Cloud" that forms along the Rocky Mountains through an inversion, a shallow pool of cool air near the ground separated from the warmer air above it. The mountains to the West hold the yellowish-brown haze cloud in place, and it appears to hover over the Denver region, sinking into the South Platte River Valley. A variety of pollutants are trapped within this haze, specifically carbon monoxide, methane, particulate matter (tiny bits of grit and dust), and nitrogen and sulfur oxides. While there are many sources of these types of pollutants, most of regulated air pollution (over 66 percent in Boulder) in Colorado, as well as the U.S., is due to motor vehicle emissions (Boulder County Clean Air Consortium as cited in City of Boulder, 2001). Although efforts to improve vehicle efficiency and reduce industrial pollution through technology are crucial, "green infrastructure" holds a key piece of the air pollution solution.

Urban forest ecosystems function as sinks for atmospheric pollution, since nearly all parts of the tree from the soil to the leaves play a part in filtering and removing gaseous and particulate pollution from the air. Trees have the ability to improve air quality efficiently and inexpensively by providing the following eco-services:

- Reduced air temperatures
- Increased oxygen levels
- Intercepted and trapped particulate matter air pollution
- Absorbed gaseous pollutants
- Bound or absorbed water soluble pollutants on leaf surface
- Reduced ozone levels

Temperature Reduction

Trees can reduce outdoor air temperatures through both shade and the process of transpiration (the evaporation of water through openings or stomata in the leaves). Trees draw water from the soil into their roots and release water through the leaf stomata, which then mixes with the heat from the air to form water vapor, cooling and adding humidity to the air. Reduced air temperatures help to reduce air pollution in the following ways:

- Mitigating the "Urban Heat Island Effect"
- Reducing the formation of temperature-dependent pollutants such as ozone
- Reducing evaporative emissions from motor vehicles
- Reducing emissions associated with higher electricity demands from air conditioning use

The Urban Heat Island Effect refers to the process by which urban areas comprised mostly of dark surfaces (e.g. concrete, asphalt, buildings, rooftops) have recorded air temperatures of up to 25 degrees hotter than forested areas of the same climate and region. These impervious surfaces store incoming solar energy, convert it to thermal energy, and release it again at night. Without vegetation to provide relief through transpiration, each subsequent day grows hotter with stored energy. By providing shade to buildings, urban trees prevent the solar energy from hitting impervious surfaces, preventing them from storing heat, as well as cooling indoor air temperatures, reducing the need for air conditioning. When building energy use is reduced, pollutant emissions from power plants are also reduced (Nowak, n.d.).

Parking lots occupy about 10 percent of the land in most major cities and are a major contributor to Urban Heat Islands (Center for Urban Forest Research [CUFR], 2002). Also, parked cars are a primary source of smog. Therefore, paved parking lots have been the focus of a number of recent studies in which results show that the addition of trees planted on a wide scale in these areas can make great improvements in air quality. For example, trees in Davis, California, parking lots were found to reduce air temperatures by up to 3° F, accompanied by ground surface temperature reductions of 36° F, and vehicle cabin temperatures by over 47° F. Even fuel tank temperatures were reduced by 7° F (CUFR, 2002). Due to the shade, less gasoline evaporated from fuel tanks and leaky hoses. Therefore, hydrocarbon emissions were reduced. These evaporative emissions contain carbon monoxide and other gaseous pollutants that are the principal components of smog.

City tree ordinances can either contribute to or improve the air pollution problem surrounding parking lots. Cities such as Sacramento, California, have parking lot ordinances that require 50 percent shade within 15 years of issuance of a development permit (CUFR, 2002). More common ordinances require one tree for a certain number of car spaces. This often results in clustering of trees on medians and very little shade. Species selection is also an important factor when planning a parking lot. Most often in the interest of space, hardy, drought-tolerant, small, low trees like the crab apple, pear, and crepe myrtle are chosen, but will never come close to providing 50 percent shade (CUFR, 2002).

Ozone

Ozone air pollution, a major component of smog, is temperature-dependent. Therefore, the decreased ambient air temperatures brought about by urban trees can reduce overall ozone formulation. However, plants manufacture and emit a variety of substances called phytochemicals, many of which are reactive Volatile Organic Compounds (VOCs), namely isoprene and monoterprene. These compounds evaporate easily into the air; when mixed with certain toxins, they can contribute to air pollution. Tropospheric, or ground level ozone pollution is formed in the atmosphere through the combined photochemical reaction of VOCs, -- nitrogen oxide (Nox) and sunlight. Figure 5 illustrates this reaction. Therefore, the highest ozone

levels generally occur in bright, balmy, urban areas where nitrogen oxide levels are higher) during the summer, when sunlight is more intense, and meteorological conditions are more stagnant (Lyons, 1999).

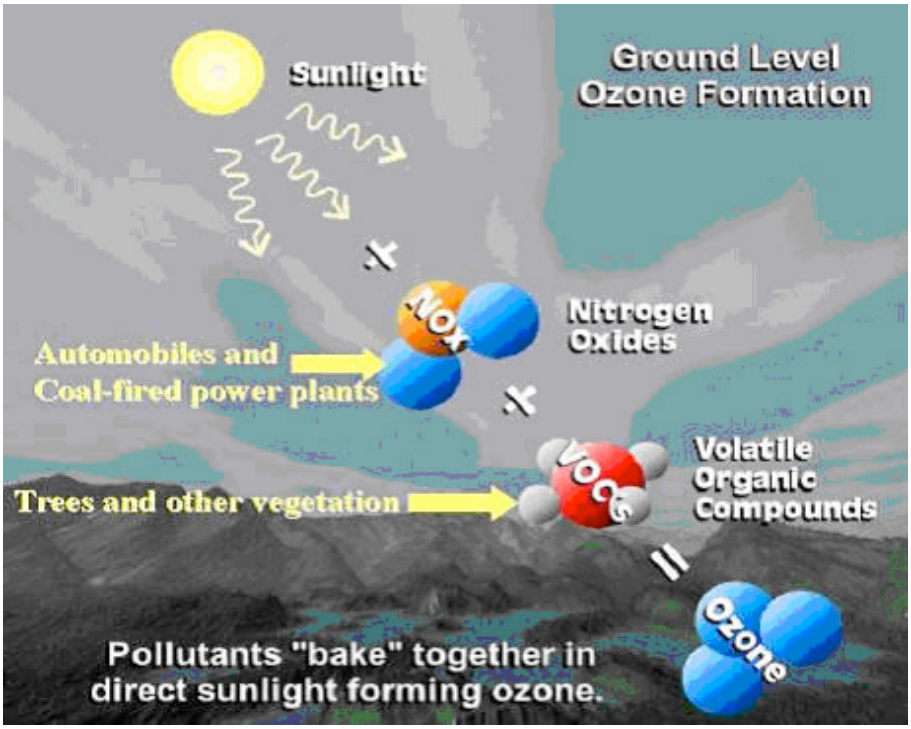


Figure 5

Although certain levels of atmospheric ozone are created naturally from biogenic emissions from trees (BVOCs), and lightning (No_x), ambient levels "in the total absence of anthropogenic (man-made) pollution are thought to be generally less than 0.02 ppm" (Galveston-Houston Association for Smog Prevention [GHASP], 1999). In fact, low levels of naturally occurring ozone are considered beneficial, as trees create their own microclimate necessary for biosystem purification (GHASP, 1999).

However, there is virtually no region where there is an absence of man-made pollution sources. Furthermore, scientists have noted dramatic increases in natural VOC levels despite clean-air laws that reduced man-made VOC emissions (Princeton, 2004). Research at the University of California, Berkeley, suggests that it is time to address the cause of this increase. "Pollution from oak trees is destroying the pine forests of the Sierra Nevada Mountains. [Studies have found that] oaks are producing between 40 and 70 percent of the ozone that is damaging and killing Jeffrey and Ponderosa Pine…" (Chennai, 2002). Added ozone is not only detrimental to other vegetation, but is also a major contributor to asthma in humans (Chennai, 2006).

Though VOC emissions from trees are naturally occurring, man's influence on the landscape is the main reason for the noted increase in vegetative-influenced smog production (Princeton, 2004). Scientists have discovered that intensified tree farming, (especially in the region from Alabama north through Tennessee and Virginia) and other land use changes (e.g. abandoned

farmland), have altered the landscape, so the species mix is no longer diversified (Purves, as cited in Princeton, 2004).

Given the correct climate for VOC formation, a non-diversified mix of trees can be a recipe for increased smog. Because the formation of VOCs is a precursor to this tropospheric ozone pollution, it is important to note that VOC emission rates from trees can vary as much as 10,000 times by species and meteorological conditions (CUFR, 2002). Though more research is needed to determine which trees are appropriate for improving air quality in different areas, a number of studies have measured different tree species in varying conditions. For example, researchers from the U.S. Forest Service analyzed forest inventory data collected on 2.7 million trees on 250,000 plots of land across the country. They combined this data with lab measurements of species-specific isoprene emission rates and nitrogen oxide emission levels to model isoprene output and smog production (Tompkins, 2005). They found that abandoned farmland has been replaced with early generations of trees that emit more VOCs. In the South, pine plantations used for their fast-growing timber supplies have increased ozone levels. This increase is due, in part, to the invasion by sweet-gum trees, in addition to the fact that fast-growing trees are heavy emitters of VOCs (Princeton, 2004).

While the Colorado climate may not be conducive to extreme VOC production, as long as NOx and sunlight are present, and ozone levels are already critical, added trees may have a larger influence than previously thought. Care taken in tree selection has the potential to improve ozone levels because trees do absorb certain levels of ozone through their biomass. As noted by Dr. David Nowak of the U.S. Forest Service, (n.d.) "In urban areas with 100 percent tree cover, short-term improvements in air quality (one hour) from pollution removal by trees were as high as 15 percent for ozone."

Particulate Matter Air Pollution

Trees and soil act as filters by intercepting tiny airborne particles of pollution such as dust, dirt, ash, etc., which have been associated with increasing respiratory and cardiovascular disease. Virtually all of particulate matter pollution (PM) is the result of combustion, (i.e., cars, lawn mowers, construction vehicles), and industrial processes that produce smoke and diesel soot. PM consists of a mixture of liquid or solid coarse (larger) particles and fine particles, from a source, or from complex chemical reactions in the air with gases such as nitrogen oxides and sulfur oxides. PMs can change from gas to particle form, and can vary by time of year, location, temperature, humidity, and wind (CUFR, 2005).

As particle pollution is transported by wind, tree leaves and branches intercept them through dry deposition; the particles settle on surfaces of the plant without the aid of precipitation. Particles can then be chemically altered by the plant tissue, metabolized and absorbed, resuspended by wind, or deposited to the ground with leaf fall (Scott et al., 1998).

One Lancaster University (UK) study determined an Urban Tree Air Quality Score (UTAQS) through a combination of site experimentation and atmospheric modeling, ranking each tree according to its air quality impact potential. In general, the study determined that "mature, mixed woodland captures airborne particles at approximately three times the rate of grassland"

(Hewitt, n.d.) Also, trees on the edge of forested areas are more effective at capturing airborne particles than trees in the center, as they have large uncovered leaf areas, and are exposed to the most wind and particle pollution.

Gaseous Pollutants

Trees remove air pollution through the process of respiration. As the tree takes in the carbon dioxide necessary for its survival through the leaf stomata, it also takes in gaseous pollutants. "Once inside the leaf, gases diffuse into intercellular spaces and may be absorbed by water films to form acids or react with inner-leaf surfaces" (Nowak, n.d.) Trees can be significant filters for pollutants such as ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide, converting them to oxygen during the process of photosynthesis.

Avoided Emissions

When building energy use is reduced through the presence of trees, whether due to reduced temperature through transpiration or through shade, pollutant emissions from power plants and vehicles are also reduced (Nowak, n.d.). The aforementioned gaseous pollutants are also reduced when emissions from these sources are avoided. It should be noted, however, according to Nowak, that "lower nitrogen oxide emissions, particularly ground level emissions, may lead to a local increase in ozone concentrations under certain conditions due to nitrogen oxide scavenging of ozone." It is therefore critical to realize the cumulative effect of additional trees before launching major tree planting initiatives.

Trees Impact Energy Consumption

The Urban Heat Island Effect

In recent years, a phenomenon referred to as the "Urban Heat Island Effect" has received increased attention (See Figure 6). The Urban Heat Island Effect describes the process by which air temperatures over urban areas comprised mostly of concrete and asphalt are up to 10° F higher than in outlying areas with more vegetation (U.S. Department of Energy (DOE) 1995, as cited in City of Boulder, 2002). Dark surfaces such as blacktop, parking lots, roofs, buildings, and other impervious surfaces store incoming solar energy, convert it to thermal energy during the day and release it again at night, creating areas of warm air over the city known as "heat islands." This effect compounds over time if each night does not cool off. Then each subsequent day gets hotter (See Figure 7). Meteorologists have noted significant differences in ambient air temperatures above a man-made surface and beneath a forested area of the same climate--as much as 25° F (DOE, 1995). Warmer summer days cause increased air conditioning use, increased energy costs, and increased levels of emissions from power plants.

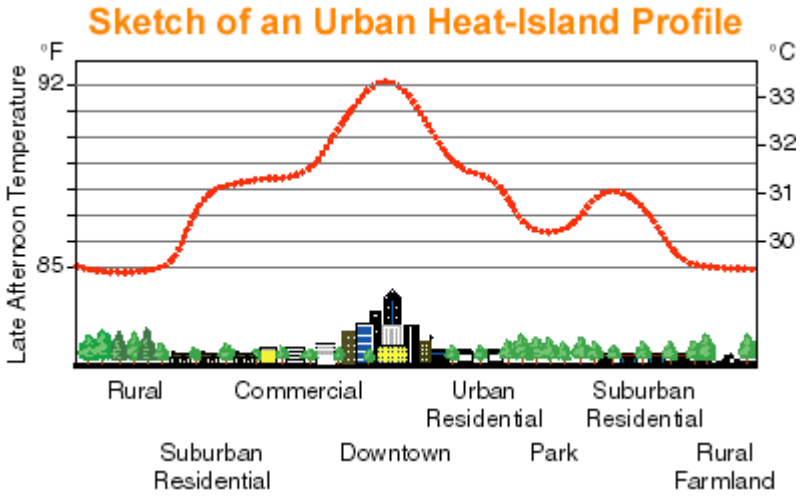


Figure 6

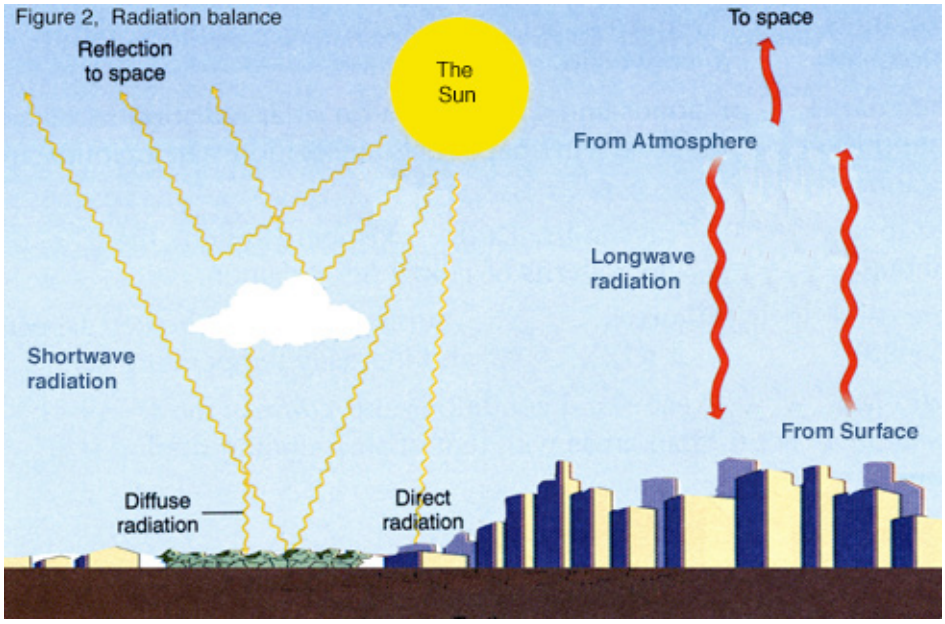


Figure 7

Urban trees are often overlooked as the natural, low-tech, inexpensive answer to these pressing issues, as they can play a significant role in reducing energy demands by providing the following:

- Shade
- Decreased indoor and outdoor air temperatures
- Reduced Urban Heat Island Effects
- Wind protection

Shade Trees

Trees directly affect both indoor and outdoor air temperatures by providing shade. Without shade, when direct sunlight strikes building surfaces (roofs, walls, and windows) these surfaces absorb solar energy and transfer heat to the inside of the building, raising indoor temperatures and keeping air conditioners running. Trees that prevent sunlight from shining in windows help to reduce indoor temperatures more than blinds do, because heat never reaches the outside of the window pane, keeping inside temperatures lower. Also, the direct shading of air conditioning units can increase their efficiency by 10 percent (DOE, 1995, as cited in City of Boulder, 2002).

The Urban Heat Island Effect can also be combated by shade trees. The direct shading of pavement prevents the initial heat transfer and energy storage that lead to higher outdoor air temperatures. In addition, when cars are parked in shaded areas, the need to run the air conditioning in the vehicle is reduced, thus using less energy (Scott, et al., 1999, as cited in City of Boulder, 2002). The Sacramento Tree Foundation (STF) estimates that its existing trees save approximately 12 percent of the total annual air conditioning energy costs, amounting to $18.5 million in savings annually (STF, 2000).

Evapotranspiration

Trees also indirectly cool outside air temperatures through transpiration, the process by which trees draw moisture from the ground through roots, and release it into the atmosphere through their stomata, or pores in the leaves (See Figure 8). The released water vapor draws heat and cools the air in the process. Transpiration, like direct evaporation, is determined by five key climatic elements:

- Solar radiation
- Air temperature
- Air humidity
- Wind speed

Solar radiation provides the heat energy required to begin the transpiration process in the leaves, as does the ambient air temperature of the air. In general, evaporation rates decline as humidity levels rise. Therefore, trees in warm, arid states such as Colorado are particularly useful for cooling the air. Wind speed will determine how quickly saturated air is replaced with drier air (Allen, 1994).

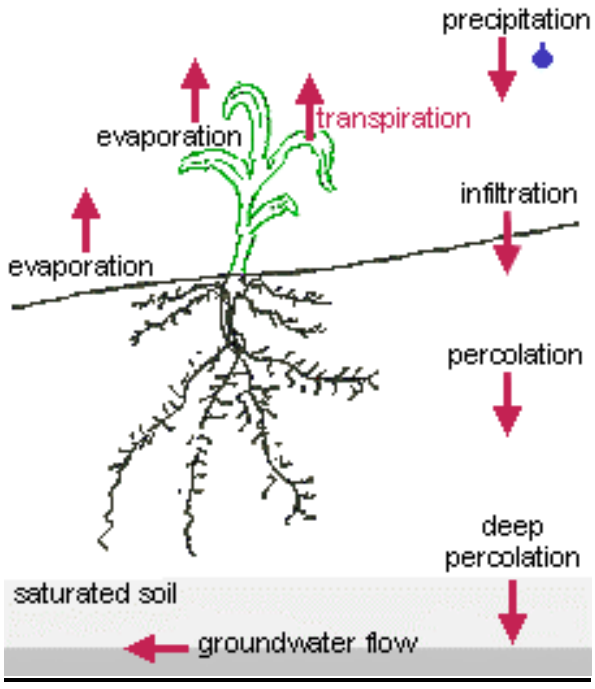


Figure 8

Proper Placement and Selection of Trees

Where trees are placed in relation to a building makes all the difference when it comes to energy savings. Strategically placed trees can be as effective as other energy-saving home improvements, such as insulation and the installation of weather-tight windows and doors. Proper trees at the proper height, especially large coniferous trees or evergreens, provide very good wind breaks, which help to reduce heating costs in the winter. In the summer, trees can save energy through shade and through the cooling effect they provide during the process of transpiration. Therefore, additional trees result in reduced fossil fuel burning at power plants to generate electricity for cooling and heating.

Strategically placed *shade trees,* (a minimum of three large trees around a home) can reduce air conditioning costs significantly (See Figures 9 and 10). Shade trees offer their best benefits when the following guidelines are applied:

- Plant *deciduous* trees, which shed their leaves in the fall. These trees provide shade and block heat during hotter months. By dropping their leaves in the fall, they admit sunlight in the colder months.
- Place these trees on the south and west sides of buildings.
- Shade all hard surfaces such as driveways, patios, and sidewalks to minimize landscape heat load.

Use *evergreens*, which retain their leaves/needles yearlong, in a planned pattern. They will serve as *windbreaks* to save from 10 to 50 percent in energy used for heating. Evergreens offer the best benefits when you:

- Place them to intercept and slow winter winds, usually on the north side of your home.
- Do *not* plant them on the south or west sides of your home, because they will block warming sunlight during the winter. These trees also provide some shading benefits during summer (Maryland DNR, 2004).

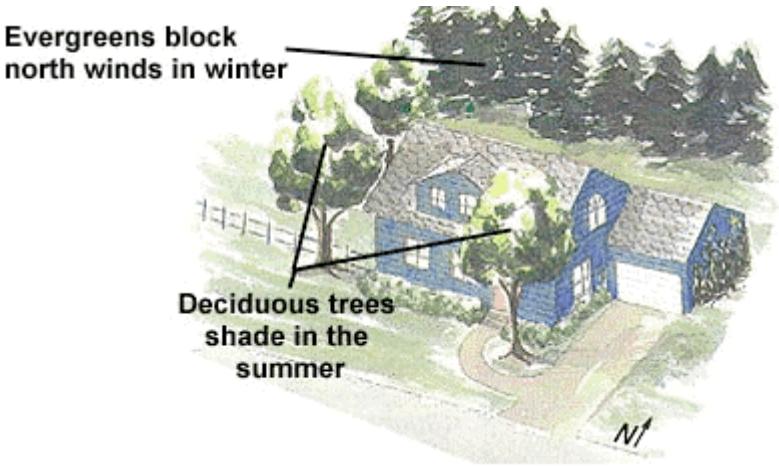


Figure 9

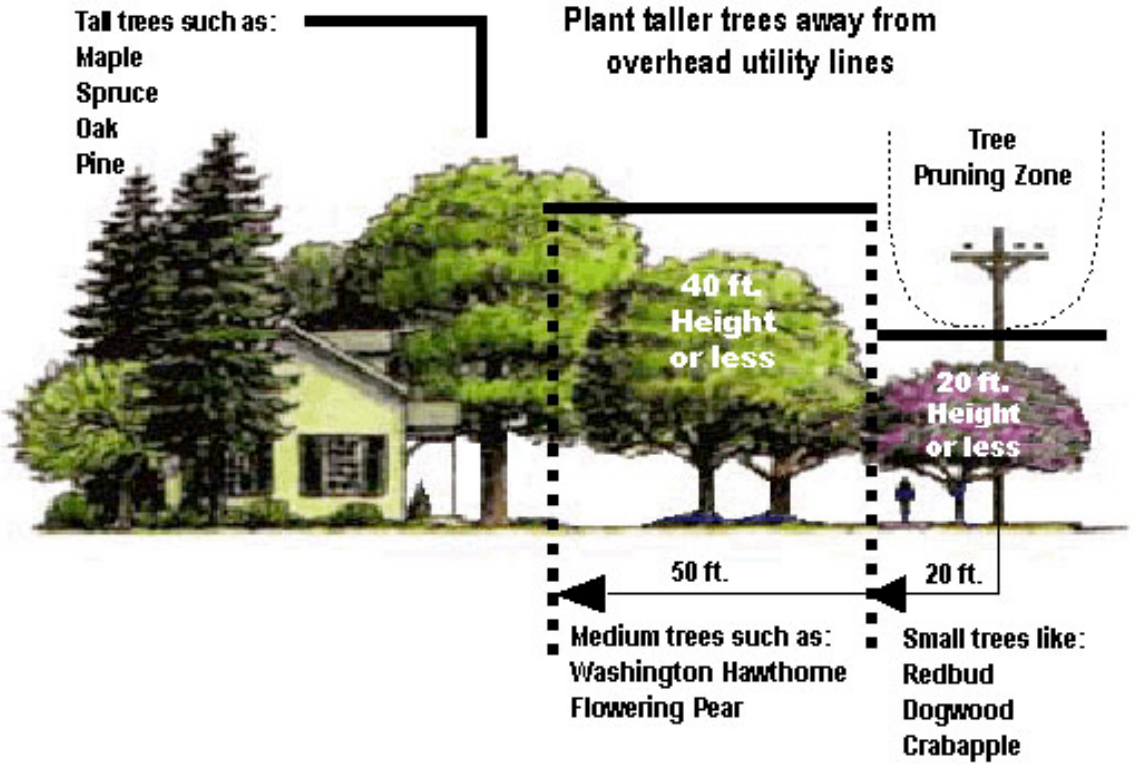


Figure 10

Trade-offs

In addition to reducing energy, trees have been proven to be a useful tool in decreasing the amount of carbon dioxide (CO_2) in the air. Trees have the ability to store, or sequester, CO_2 as they grow during the photosynthesis process, in which solar energy, water, and CO_2 are

absorbed, converted into energy, or stored in the plant's biomass. Though carbon dioxide occurs naturally in the atmosphere, human industrial activities have caused CO_2 levels to increase by 30 percent since 1950, half of which has occurred over the last 30 years (YPTE, n.d). Because carbon dioxide from fossil fuel combustion now constitutes 82 percent of greenhouse gases contributing to global warming, trees may become a crucial element in returning the world's carbon cycle to normal levels (NEIC, 2004).

However "The question isn't just 'Can we store carbon in trees, and how much do we gain from that?' The question is also 'What are the other gains and losses for the environment?' We have to be smart about our sequestration policies" (Basgall, 2004). Though trees offer significant opportunity for energy savings and improved air quality, there are unavoidable environmental trade-offs to consider in the attempt to use vegetation to reduce energy. Especially in areas of the arid West where trees do not naturally grow, it is critical to evaluate tree species choices, not only for the highest amount of energy savings, but also for the least amount of water use possible. Water is a limited resource in Colorado, and additional trees may have a long-term effect that may outweigh some of the benefits if not carefully studied. For example, decreased stream flow as a result of increased trees may result in not only less water for human and animal consumption, but also nutrient depletion and increased soil salinity and acidity (Basgall, 2005).

Trees Impact Water Quality

Land Use Changes and Vegetation: Effect on Water Quality

"Water quality is the end result of the individual actions of all the 'neighbors' in a watershed" (USDA, 2004). As the population grows and urban areas become more congested, human activities degrade the quality of the water in the streams, lakes, estuaries, wetlands, and aquifers on which we depend. Excessive sedimentation, pesticides, and fertilizers are major contributors in water contamination (USDA, 2004). A change in land use from vegetated land into impervious surfaces has led to the following environmental problems:

- Increased flooding
- Increased pollution in water resources
- Increased sedimentation in water resources
- Increased erosion
- Decreased groundwater recharge
- Decreased wildlife habitat

The primary reason that changes in land use cause a decrease in water quality is because displacement of permanent vegetation such as trees, shrubs, and grasses by community development (or annual crops) increases stormwater runoff significantly. Stormwater, by definition, is water from rain or melting snow that fails to percolate into the soil or get soaked up by vegetation, but instead moves across the surface of the ground, pouring into storm sewers (Hopkins, 1997). In urban areas, this rapidly moving runoff causes flooding and transports high levels of sediment and chemicals, as well as oil, antifreeze, and salt from city streets and parking lots into water sources (USDA, 2004). In addition, landscape and lawns in urban areas often require the use of fertilizers, herbicides, and pesticides that are carried off into water resources by runoff. Drains are often overwhelmed, causing flooding in homes and businesses, polluted drinking water, and destroyed wildlife habitat. This is a particularly serious problem for municipalities that co-mingle their wastewater and stormwater, as sewage will wind up in rivers and streams during a system overflow (Hopkins, 1997).

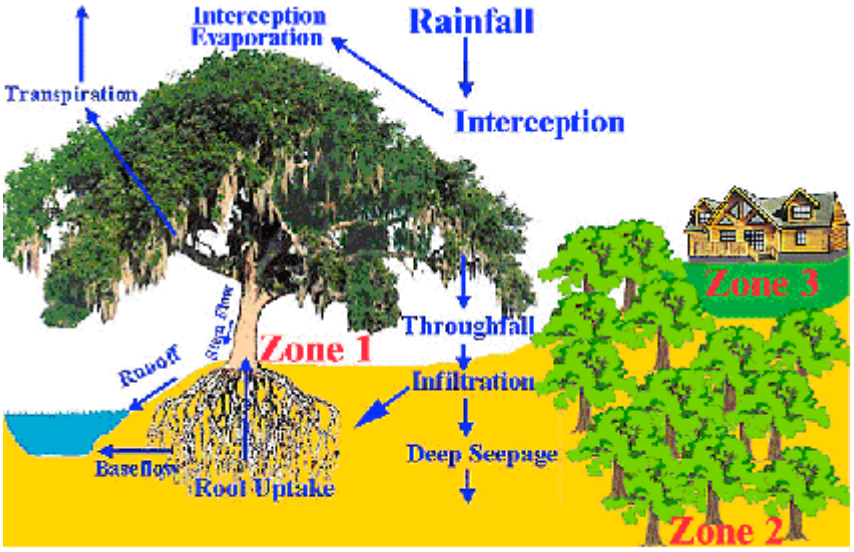
Less directly, the removal of trees and other vegetation also leads to higher water temperatures in rivers and lakes. The lack of shade heats surface water that runs into these bodies of water, disturbing the balance of the aquatic ecosystem.

Trees benefit water resources in urban areas both by improving water quality and decreasing stormwater runoff. Many factors contribute to the degree of benefit that urban trees provide to water quality, including slope of the site, percentage of tree canopy cover, perviousness of the soil, and amount of precipitation.

Trees and Stormwater Management

Trees and other vegetation function as natural stormwater management tools that are destroyed through the process of urbanization. Trees manage stormwater above the ground, at the surface level, and below the ground, performing a number of ecological services (See Figure 11):

- Above ground effects
  - Interception: Trees intercept precipitation on leaves, branches, and trunks, slowing movement to the ground, and preventing rapid runoff. Trees also intercept and trap wind-blown dust before it enters streams and lakes.
  - Absorption: The leaves, stems, and trunks of trees absorb a small portion of precipitation.
  - Evaporation: Some of the intercepted precipitation is evaporated back into the hydrologic cycle.
- Surface level effects
  - Storage: Fallen leaves and other organic material act like sponges, holding precipitation in place, slowly releasing water into the soil, and preventing surface runoff.
  - Dispersion: Roots and trunks of mature trees create hollows on the ground that hold and disperse runoff that prevents erosion.
- Below ground effects
  - Infiltration: Tree roots, leaves, and other organic matter create pore spaces in the soil, increasing infiltration of precipitation down into the ground.
  - Permeation: Organic tree matter increases the capability of soil to hold moisture. Deep roots improve the transfer of water from upper soil horizons into lower soil levels.
  - Filtration: Tree roots are natural pollution filters, taking up and processing pollutants such as nitrogen, phosphorus, and potassium through the soil and water.



The effects of trees and vegetation on the water cycle.

Figure 11

Phytoremediation

Phytoremediation is a rapidly developing field of bioremediation, or "cleanup technology" which uses trees and green plants to "destroy, remove, contain, or otherwise detoxify environmental contaminants" (Cunningham et al., 1996). Certain plants are capable of cleaning up soil, sediment, and water and even the atmosphere contaminated with metals and/or organic contaminants such as oil, solvents, pesticides, and polyaromatic hydrocarbons (PAHs) by a number of different natural processes. For example, through one process of phytoremediation called "phytovolatilization," plants take up water and organic contaminants through the roots, transport them to the leaves, and release a detoxified vapor into the air. Through "phytodegradation," organic contaminants are absorbed inside the plant, metabolized (i.e. broken down) into non-toxic molecules through the natural chemical process of the plant (Zynda, 2001). Plants species are selected based on their potential to evapotranspirate groundwater, and growth rate, depth of root zone, and ability to tolerate chemical contamination. Depending on climate and type of contamination, wetlands plants and grasses or trees such as Poplars may be among the most useful for improving water quality with vegetation.

In recent years, a number of companies have begun offering phytoremediation services, as researchers are finding it very beneficial treatment technology, even though there are some limitations. Advantages and disadvantages follow:

Advantages	Disadvantages
Easy to implement and maintain	May depend on climatic conditions
Low-cost compared to other clean-up methods	May take several years
Environmentally friendly and aesthetically pleasing	Possible food chain contamination
Fewer emissions	Limited to places where plants grow well, and contamination must be fairly shallow
High public acceptance	Unfamiliar to regulators and lawmakers
Solar driven	Possible groundwater contamination

Trees and Wastewater Treatment

Conventional wastewater treatment is based on a relatively simple, though extremely expensive process: first, remove as much organic waste as possible through settlement and filtration, then convert the soluble organic matter into biological tissue that can be physically removed, then destroy the rest through oxidation to carbon dioxide (Wickham, 1999). However, trees provide a natural alternative to cement sewer systems, because they can filter and process wastewater, providing a safe, economical means of wastewater treatment and disposal (USDA fact sheet, 2002). In fact, "tree plantations treat wastewater for about 60 cents per 1,000 gallons, about one-half to one third the cost of traditional secondary treatment methods." (Wickham, 1999) Rapidly growing tree species can effectively uptake runoff from irrigated fields or lawns, livestock operations or municipal and industrial wastewater (USDA Agroforestry, 2002).

Most watersheds support a mixture of land uses, such as residential communities, urban centers, and even agricultural areas that are often located within and around urban areas. Therefore, an integrated approach to managing water resources is necessary to maintain water quality. Trees are useful in all areas of water management, as they provide a number of ecological services, serving as pollution filters, wastewater treatment tools, windbreaks, and flood control devices. They hold soil in place, preventing erosion and damage to property and riverbanks, thereby protecting wildlife habitat. There are many ways to integrate trees and other vegetation into water management systems, in the form of urban forests, wetlands, and other green infrastructure, that is far less expensive than cleanup technology or man-made drainage systems.

"Since 1972, the United States has spent $600 billion on wastewater treatment technologies" alone, and that does not include the millions spent each year on stormwater management facilities (Halpern, 2002). It is crucial that we focus on an integrated approach of natural and man-made facilities, and utilize the right trees in the right place for their full potential.

Trees Impact Water Supply

Trees and Diminishing Water Supply: Water Supply, Demand, and Use Along the Colorado Front Range

Water is a limited and precious resource in the semi-arid plains which include Colorado, so precious that every drop of the Colorado River is used an average of 17 times. In the American West, water left in the stream was considered to be wasted. Water development in Colorado has enabled farmers to raise crops in a desert and city planners to turn arid prairies into heavily populated, green cityscapes (Gleick, 2002). This development has had a significant impact on the landscape of the Front Range and water consumption behavior. In order to address how tree planting affects limited water supplies in Front Range communities, the following sections provide on overview of:

- The Front Range climate and average annual precipitation
- Colorado's water consumption and usage
- Recent drought and water conservation measures
- New development with growing urban populations and water demands
- Sustainable water use and proper tree care

The Front Range

The majority of Colorado's population lives along the Front Range, the land east of the foothills of the Rocky Mountains extending from Fort Collins and Greeley in the north to Denver and south to Colorado Springs and Pueblo. Denver's water supply is mainly runoff from snowmelt in the Rocky Mountains (Denver Water, 2006). Most of Colorado's water supply is on the Western Slope, the land west of the Rocky Mountains, which drains the Colorado River Basin. Therefore, the water supply is on the Western Slope, whereas most of the demand is in the Front Range where the largest urban centers are found. Colorado's average rainfall depicted in the graphic below illustrates the disparities between rainfall from region to region.

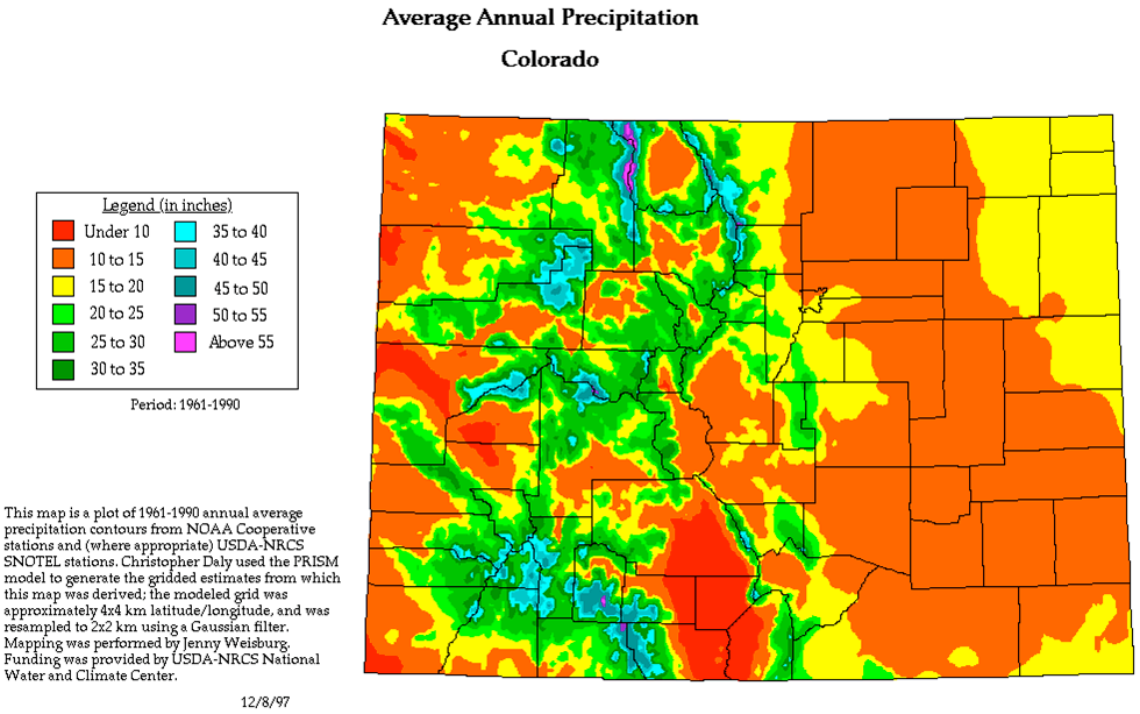


Figure 12

The Front Range is naturally a "semi-arid, shortgrass prairie that would have few trees without irrigation" where periods of drought are common. The trees planted in communities along the Front Range are often not native and are accustomed to environments that receive over 30 inches of rainfall a year (Fort Collins, 2006). Denver's average rainfall is 15.4 inches a year, and Fort Collins is similar, receiving 15 inches per year (See Figure 12). According to the City of Fort Collins, even established trees need between 22 and 25 inches of water each year to grow at a moderate rate; therefore, most trees along the Front Range require some irrigation.

Colorado's Water Consumption

> "Water in the western United States developed under institutions designed to encourage settlement and consumptive, off-stream use. These institutions generated a wealth of subsidies for water power, agriculture, and land, which led to disproportionately high water consumption and a disregard for resource conservation (Gleick, 2002)."

Water use in Colorado is often still governed by a "use it or lose it" approach. The principle stems from the fact that stream water is constantly flowing and any water left in the stream by one person would be used by another, hence the "use it or lose it" phrase (Green 2002). A result of this rule-of-thumb is habitual or consumption accustomed to wastefulness. For instance, the average Coloradoan uses over 200 gallons of water every day compared to the average Arizonian who uses only 160 gallons (CSUCE, 2006).

Currently, agricultural irrigation uses 80 percent of all diverted surface water in Colorado; demand is expected to increase to 86 percent by 2030. Surface water is water that sits or flows above ground in lakes, oceans, rivers, and streams. At approximately 7 percent, municipal water use is quite small in comparison, but is expected to grow as population approaches 7million by 2030. Groundwater resources are defined as water existing below the earth's surface in underground streams and aquifers or saturated open spaces below the water table. Groundwater resources are not sufficient to augment the tremendous use of surface water throughout Colorado, and throughout the Denver metropolitan area, regional aquifers are in decline. Therefore, with limited and fluctuating water availability, increased use cannot occur in both agricultural and municipal sectors while meeting in-stream flow requirements, requirements that, by law, allocate water to remain in the stream for environmental benefits (Merriman & Janicki, 2005).

Drought and Conservation

A few years ago, most large trees needing more than the average rainfall received supplemental water as a result of lawn watering. However, the recent drought has brought wasteful water uses under scrutiny. Today, many Front Range communities, such as Denver, Fort Collins, Castle Rock, and Aurora, encourage the adoption of landscaping techniques that are more appropriate for the climate. The steps that Front Range communities have taken towards water conservation vary considerably. Aurora, for example, has outlawed hand-watering. Many communities such as Denver, recommend (but do not require) landscapes using less water, such as Xeriscapes. Most cities implement water restrictions during shortages, but Parker has a "voluntary" water schedule, despite the city's reliance on an aquifer for its water. Castle Rock, on the other end of the spectrum, does require that the principles of Xeriscaping be used.

Municipalities, unlike agricultural water users, employ primary treatment to provide potable water to domestic taps. In addition, reclaimed sewage effluent and non-potable sources are used for landscape irrigation where possible. Even with these alternative irrigation sources, 40-50 percent of domestic drinking water is used to irrigate urban landscapes. The cost of treatment and limited supply of raw water has forced most municipal water providers to enact outdoor water use restrictions that range from prohibited use to tiered pricing – a system that charges higher prices for bigger water users to encourage conservation. These restrictions vary, depending on the community and yearly precipitation. This, in turn, has encouraged many municipalities to promote less water consumptive landscapes, known as Xeriscapes that also maintain an aesthetic appearance (Litus, 2006). According to the City of Castle Rock, "by following the seven principles of Xeriscape**,** between 40 and 60 percent of the water used in traditional landscapes can be conserved" (2006). The seven principles of Xeriscaping are

1. Plan and design
2. Create practical turf areas
3. Select low water plants
4. Use soil amendments
5. Use mulches
6. Irrigate efficiently
7. Maintain the landscape properly

At the same time Front Range communities are actively pursuing additional water sources, including groundwater resources in South Park, the San Luis Valley, and the Gunnison River Basin. Resistance to intermountain diversions – the "removal of water from its natural course or location by canal, pipe, or other conduit" (Waskom & Neibauer, 2004) - is strong throughout rural communities that do not share the desire for growth and landscape development that is concentrated in the Front Range urban corridor (Litus, 2006).

The issues and conflicts associated with water supply and demand in Colorado are complex and challenging. Methods of improved water conservation deserve urgent attention. In a state with extensive agricultural irrigation and a growing population, management of limited water resources attempts to balance economic concerns and municipal demands with recreation and environmental requirements (Litus, 2006).

Development and Water

Rapid population growth along the Front Range creates one main issue concerning water supply and demand with regards to trees.

> "Because of exploding population growth, the Denver metropolitan area must now deal with conflicting claims between urbanization and preserving the natural resources needed to sustain urbanization" (USGS, 2002).

While agriculture and industry demand the largest portion of water consumed along the Front Range, individual consumption is also substantial. According to Colorado State University's Cooperative Extension (CSUCE, 2006), "outdoor water use accounts for about 50 percent of the residential water use in the Front Range urban area, most of which is used on turf" (2006). In other words, as more people move to Front Range communities, the demand for indoor and outdoor water consumption increases. Tree planting practices, therefore, need to ensure that the right tree is planted in the right place, and that it is properly cared for (CSUCE, 2006).

Sustainability and Proper Tree Maintenance

Healthy mature landscapes provide notable benefits. These include a reduction in household energy consumption, sequestration of carbon dioxide emissions, improvement in air quality, reduction in stormwater runoff, and an increase in property values due to the importance that people place on aesthetically and psychologically inspiring surroundings. These benefits are tangible, but the landscapes that provide them may have significant irrigation requirements (Litus 2006).

The average life span of a tree in Colorado is eight years (CSUCE, 2006). Many trees planted are not provided with enough space for the tree to grow to its potential or an adequate amount of water. Denver Water recommends that the "critical root zone," as depicted in Figure 13 by the box drawn around the roots, be watered, but researchers at Colorado State University's Cooperative Extension are discovering that the "critical root zone" for Colorado is much larger.

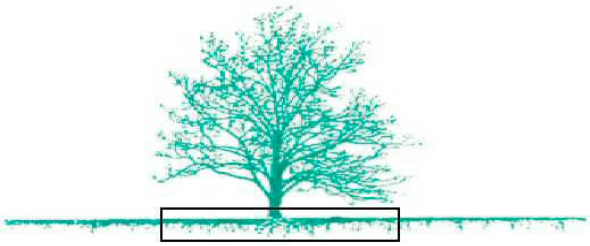


Figure 13

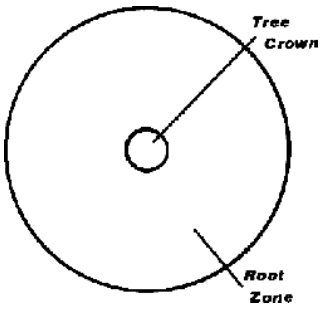


Figure 14

Proper watering is essential; in Colorado, a tree's roots extend outward to several times the canopy's size, as shown in Figure 14, because of the heavy clay soil common in the Front Range – this entire root area should be watered. In times of water restrictions, trees should be given higher priority than lawns for the simply reason that it is easier and less costly to replace a lawn than it is to replace a 20-year-old-tree (Fort Collins, 2006). Successful tree planting depends on:

1) Functional design
2) Plant selection
3) Pre-planting handling
4) Planting techniques
5) Post-planting care

Trees with restricted rooting space will grow slower, be smaller, and have a shorter life span. Roots may grow under sidewalks and driveways, but typically do not grow under streets because of soil compaction (CSUCE, 2006). Figure 15 shows root area required for each diameter at breast height (DBH) of a tree.

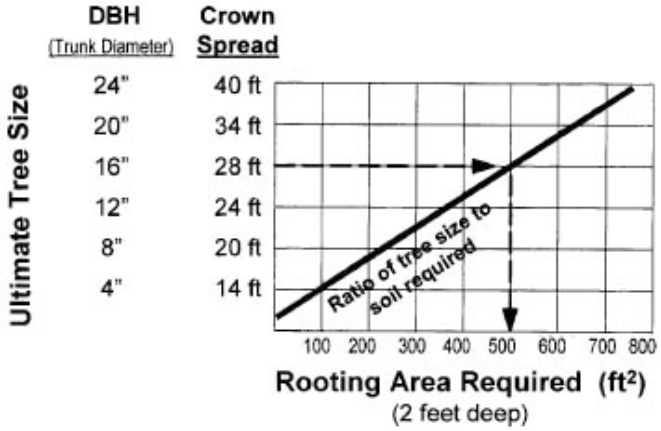


Figure 15

Conclusion

Great potential exists for urban forest management strategies to lessen the effects of global climate change while improving air quality, and energy and water conservation. However, they must include well-thought-out plans to utilize the best possible mix of species to accomplish the pollution reduction goals for a given climate. Particularly, since we are all stakeholders in the quality of our air, additional research is needed to fully understand the complex impact of trees on environmental conditions. Perhaps most important is the contribution of VOCs by trees. According to Drew Purves, a lead researcher at Princeton University, "If we don't understand what's going on with biogenic VOCs, we are not going to be able to weigh different air-quality strategies properly. It's a big part of the puzzle that really needs to go in there with the rest." (Purves, as cited in Princeton, 2004).

Also, planting trees in Colorado requires special consideration of other factors to ensure the health of the trees, including a proper water regimen and adequate space. Limited water resources are already stressed in Colorado, and demands on supply will only increase as a result of growing urban communities. Conservation measures taken in agriculture, industry, and in and around the home will ease the demand on the limited supply. Trees will continue to provide many benefits as long as the trees planted are appropriate for Colorado's semi-arid climate and are properly maintained.

Finally, with proper placement, the positive effect of trees on a building's direct energy consumption is well understood. More abstract is the concept of CO_2 reductions from energy production. However, current studies indicate that in general, the amount of CO_2 reduced from avoided CO_2 emissions is greater than what the trees themselves sequester. Therefore, by increasing energy conservation with properly selected shade trees for the Colorado climate, CO_2 emissions, water use, and stormwater runoff will be reduced, without the use of man-made infrastructure or expensive technology.

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Figures

Figure 1: Global Climate Change Graph:
http://www.climatechange.gc.ca/english/climate_change/earth.asp
Figure 2: http://www.epa.gov/sequestration/images/cycle1.gif
Figure 3: http://www.nationalgeographic.com/xpeditions/lessons/08/g68/brainpopphoto.html
Figure 4: http://www.greenhouse.crc.org.au/about_greenhouse/carboncycle.cfm
Figure 5: Ozone: http://www.osc.edu/research/pcrm/transport/pollutants.shtml
Figure 6: adaptation.nrcan.gc.ca/. ../health-03_e.asp
Figure 7: telstar.ote.cmu.edu/.../ s2/07ghe_climchg.shtml
Figure 8: www.ca.uky.edu
Figure 9: http://www.dnr.state.md.us/forests/publications/urban5.html
Figure 10: www.fortworthgov.org
Figure 11: www.treelink.org
Figure 12: www.wrcc.dri.edu
Figure 13: (CSUCE, 2006)
Figure 14: (CSUCE, 2006)
Figure 15: (CSUCE, 2006)

Greenhouse Effect Animation available at
http://www.epa.gov/globalwarming/kids/greenhouse.html
And http://www.planetguide.net/book/chapter_3/greenhouse_effect.html

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