The Tree Project
Integrated Urban Environmental Improvement Through Tree Selection and Mangagem
Trees and Air Quality

Trees and Air Quality - Background

Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment. The four main ways that urban trees affect air quality are 1) Temperature reduction and other microclin power plants. (Mcpherson,) Some of the major air pollutants and their primary sources are: 1) Carbon Dioxide: Burning oil, coal, natural gas for energy. Decay and burning of forests. 2) Sulfur Dioxide: Burning coal to generate e automobile exhaust gases. Ozone is a major pollutant in smog, and of particular concern to the Front Range. 5) Methane: Burning fossil fuels, livestock waste, landfills. 6) Nitros Oxide: Burning fossil fuels and automobile exhau smoke). Trees also absorb Carbon Dioxide (CO2).

Technical Issue	Benefit/Potential Effect	Cost/Potential Issues
Trees and Air Temperature	Trees cool the atmosphere through evapotranspiration, (the evaporation of water through leaves). The tree absorbs water through its roots, and evaporates it through the pores in the leaves. This process uses heat from the air to convert water contained in the vegetation into water vapor (EPA, 2005)	While this process reduces air temperatures, it does add moisture to the air.
	Trees improve air quality by reducing temperatures, thereby slowing the rates at which many air pollutants are formed and volatized. Reduction of air temperatures in summertime help to reduce pollution in 3 ways: 1) By reducing chemical reaction rates in the atmosphere that result in ozone formation. Lower temperatures reduce ozone-precursor emission rates, thus influencing ozone formation. 2) By decreasing temperature-dependent emissions of hydrocarbons from both natural and manmade sources. 3) By decreasing emissions of pollutants from electric power plants due to reduced air conditioning demands (McPherson, 2003).	Although trees usually contribute to cooler summer air temperatures, their presence can increase air temperatures in some instances. In areas with scattered tree canopies, radiation can reach and heat ground surfaces; at the same time, the canopy may reduce atmospheric mixing such that cooler air is prevented from reaching the area. In this case, tree shade and transpiration may not compensate for the increased air temperatures due to reduced mixing (of layers of air/chemicals) (Nowak, n.d)
	Trees combat the "urban heat island effect" by lowering air temperatures through evapotranspiration, similar to the way a swamp cooler works. (the urban heat island effect refers to the process in which typical urban surfaces, comprised mostly of concrete and asphalt, get much hotter during the day than do vegetated surfaces. These man-made surfaces store incoming solar energy, converting it to thermal energy, and releasing it again at night, created areas of warm air over the city known as heat islands. The effect is compounded over many hot days). Trees and other greenspace within individual building sites may lower air temperatures 5 degrees F compared to outside the greenspace. At larger scale urban areas, climate differences of more than 9 degrees F have been observed. (According the the Boulder report, the temperature measured directly above man-made surfaces can be as much as 25 degrees hotter than the temperature beneath a forested area).	
Trees and VOCs (ozone formulation)	Ozone pollution is formed in the atmosphere through the combined photochemical reaction of NOx, VOCs, and sunlight. Therefore, the highest ozone levels generally occur in the summer, when sunlight is more intense and meteorological conditions are more stagnant (Lyons, 1999). Reduced air temperature due to increased trees can improve air quality because the emission of many ozone-forming chemicals (volatile organic compounds or VOCs) are temperature dependent, decreased ambient air temperature can reduce overall ozone formulation (Nowak, n.d.)	Many species of trees and shrubs emit volatile organic compounds (VOCs) (or hydrocarbons) which are referred to as Biogenic VOCs (or BVOCs). Isoprenes and Monoterpenes are common BVOCs that contribute to ozone formulation. VOCs react with sunlight, and anthropogenic oxides of nitrogen (Nox) (air pollution from gasoline powered vehicles or plants) to produce ozone air pollution, and carbon monoxide. However, VOC emission levels are plant species specific by as much as four orders of magnitude. Also, BVOCs are strongly dependent upon environmental factors (temperature, light).
Trees and Air Pollutants	Trees remove air pollution (including nitrogen oxides, sulfur oxides, particulate matter, and ground-level ozone pollution) (EPA, 2005) through two ways: 1) Dry desposition: gases or tiny airborne particles (particulate matter or PM) are transported to a surface of the plant (mainly leaves). Tree canopies intercept particulate matter air pollution 24 hrs. a day. Most particulate matter pollution are retained on the plant surface (Nowak, n.d.) Gaseous pollutants are only absorbed during daylight hours during in-leaf season (Lyons, 1999). 2) Transpiration or "Uptake": gases such as ozone and NOx are absorbed into the leaves via tiny pores in the epidermis of the leaf while they take in water and CO2. 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.) Ample water is critical to maximizing gaseous pollutant removal (Nowak, 1994 as cited in Lyons, 1999).	Vegetation is only a temporary retention site for many atmospheric particles. Some of the intercepted particles are often re-released into the atmosphere, e.g. they are washed off by rain, or dropped to the ground with leaf/twig fall. (Nowak, n.d.).

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nate effects. 2) Removal of air pollutants. 3.) Emission of volatile organic compounds and tree maintenance emissions. 4) Energy effects on buildings, which in turn influence emissions from :lectricity. 3) Hydrogen floride and silicon tetrafloride: Aluminum and phosphate fertilizer production, oil refineries, and steel manufacturing. 4) Ozone: Chemical reactions of sunlight on st. 7) Chloroflorocarbons: Air Conditioners, refrigerators, industrial foam. (Maryland Dept. of Natural Resources) Trees help to settle out, trap and hold particle pollutants (dust, ash, pollen and

Notes	Sources
The leaves on a healthy 100 ft. tree can take 11,000 gallons of water from the soil and release (or "breathe") it into the air in a single growing season. A mature tree with a 30-foot crown transpires approximately 40 gallons of water per day. Evapotranspiration alone can result in peak summer temperature reductions of 2 to 9°F (1° to 5°C). (EPA, 2005)	EPA. (May 18th, 2005). Trees and Vegetation. Accessed via: http://www.epa.gov/heatisland/strategies/vegetation.html
	McPherson, E. G. et al., (March, 2003). Northern Mountain and Prairie Community Tree Guide: Benefits, Costs and Strategic Planting. Accessed via: http://cufr.ucdavis.edu/products/cufr_258.pdf
	Nowak, D.J. The Effects of Urban Trees and Air Quality. USDA F.S. Accessed via: http://www.fs.fed.us/ne/syracuse/gif/trees.pdf
	Nowak, D.J. The Effects of Urban Trees and Air Quality. USDA F.S. Accessed via: http://www.fs.fed.us/ne/syracuse/gif/trees.pdf
In atmospheres with low nitrogen oxide concentrations (e.g. some rural enviroments) VOCs may actually remove ozone (Crutzen, et al. as cited in Nowak, n.d.)	
Research shows that large trees remove considerably more pollution than smaller ones: a healthy tree with a trunk-diameter of 30 inches removes about 70 times more pollution than a tree with a three-inch trunk (EPA, 2005).	1) Nowak, D.J. The Effects of Urban Trees and Air Quality. USDA F.S. Accessed via: http://www.fs.fed.us/ne/syracuse/gif/trees.pdf 2)Lyons, C. E. (1999). Biogenic Emissions of Air Pollution: Impact of Tree Planting on Urban Air Quality. 3) EPA. (May 18th, 2005). Trees and Vegetation. Accessed via: http://www.epa.gov/heatisland/strategies/vegetation.html

	Trees effectively remove many toxic chemicals, such as formaldehyde and benzene, from the air and soil.	Urban trees require energy-burning maintenance activities which involve burning fossil fuels to maintain vegetation structure. These emissions should be considered in the net effect of urban forests on air quality. Equipment used to plant, maintain and remove trees include vehicles, chain saws, back hoes, leaf blowers, chippers, and shredders. Emissions (including manufacturing) include carbon dioxide, VOCs, carbon monoxide, nitrogen, sulfur dioxide and particulate matter (Nowak, n.d.)
		Urban trees may have a negative effect on air quality by reducing the dispersion of pollutants within the urban canopy layer, i.e. trapping pollutants within the canopy (McPherson, et. al, 1999).
Trees and Carbon (CO2) Sequestering	Urban trees provide a natural way to mitigate the increase of atmospheric carbon attributed to global growth. Trees remove (sequester) carbon from the atmosphere through photosynthesis, extracting carbon dioxide from the air, separating the carbon atom from the oxygen atoms, and returning the oxygen to the atmosphere. Because trees store carbon in their biomass (leaves, trunk, stems, roots, branches) and sequester additional carbon in the process of growth, they act as a "sink" for the excess CO2 produced in urban areas. Generally, trees are comprised of 45% carbon, 50% water, and 5 % minerals, but vary with species (Boulder report). As long as trees are actively growing, their rate of uptake of CO2 through photosynthesis is greater than their release of that gas through respiration, and the net results is an overall reduction of CO2 in the atmosphere (McPherson and Simpson, 1999).	Carbon is released when trees die and decay, and a small amount is released each year when the leaves of deciduous trees fall to the ground (Boulder report,)
	The soil beneath vegetation is often overlooked as a crucial component of natural carbon sequestration. Soil actually has a higher capacity to store carbon than the vegetation itself, as it can hold two to three times the volume of above ground carbon in the form of dead organic matter, or "humus". With the addition of urban trees, soil erosion is reduced due to their far-reaching root systems which physically hold the soil in place; therefore retaining large amounts of underground stored carbon (Boulder report)	CO2 is released by vehicles: chain saws, chippers, and other equipment during the process of planting and maintaining trees (McPherson and Simpson, 1999).
	Shade trees indirectly reduce the need for air conditioning and power generation, (major sources of carbon emissions) therefore trees are responsible for preventing more carbon from being released than they remove through sequestration. This is referred to as "avoided carbon savings"	Space limitation: urban areas have a variety of other land uses, and therefore will never be able to achieve the level of carbon sequestration of a natural forestland.
	Because of higher tree densities, rural forests sequester twice as much CO2 as urban forests per unit land area, however, because urban trees tend to grow faster than rural trees, they sequester more CO2 ona per-tree basis (Jo and McPherson as cited in McPherson and Simpson, 1999).	Carbon sequestration depends on tree growth and mortality, which in turn depends on species composition, age structure, and health of the forest. Newly planted forests accumulate CO2 rapidly for several decades, and then annual sequestered CO2 will decline. Old-growth forests can release as much CO2 from decay as they sequester from new growth (McPherson and Simpson, 1999).
		Although rapidly growing trees sequester this advantage can be lost if the rapidly growing trees die at younger ages (McPherson and Simpson, 1999).
Trees and Oxygen	Trees and other vegetation produce vital oxygen, emitting it through their biomass.	

Trees and Greenhouse Gases - Background

While trees emit some of the gases that contribute to the greenhouse effect naturally, research shows that planting trees helps to curb global warming by emitting oxygen and sequestering gases and particulate matter. Greenhouse Gas pass through the Earth's atmosphere, but prevent most of the outgoing infrared (heat) radiation from the surface and lower atmosphere from escaping into outer space. These gases are generated through both natural and anthropogenic byproduct of burning fossil fuels. Other greenhouse gases include methane (from agricultural sources), Ground-Level Ozone (O3) that occurs near the surface is a major component of smog, Nitrous Oxide (N2O) produced by vehicle

Technical Issue	Benefit/Potential Effect	Cost/Potential Issues

Is Denver still a non-attainment area? -The metropolitan Denver area was designated on April 30, 2004 as nonattainment, but with a deferred effective date of this designation (initially to September, 2005) because of the area's participation in EPA's ozone Early Action Compact (EAC) program. The Denver area counties designated as nonattainment (deferred) were; all of Adams, Arapahoe, Boulder, Broomfield, Denver, Douglas and Jefferson along with the southern portions of Weld and Larimer counties. (EPA, 2005)	1) Nowak, D.J. The Effects of Urban Trees and Air Quality. USDA F.S. Accessed via: http://www.fs.fed.us/ne/syracuse/gif/trees.pdf 2) EPA (March 31, 2005). Denver's Ozone Designation. Accessed via: http://www.epa.gov/region8/air/denverozone.html
	McPherson, E.G. Simpson, J. (November 1999). Reducing Air Pollution Through Urban Forestry. Accessed via: http://cufr.ucdavis.edu/products/11/cufr_73.pdf
Approximately 97% of total CO2 emissions would occur even if humans were not present on earth, due to the CO2 release during natural decay of organic matter in forests/grasslands. This release of about 196 billions tons of CO2 annually is nearly balanced by physical/biological processes: sea water into which CO2 dissolves, and the growth of plants are natural reservoirs of CO2 (McPherson and Simpson, 1999). Carbon storage and sequestration can be modeled with CITYgreen	McPherson, E.G. Simpson, J. (January 1999). Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. Accessed via: http://cufr.ucdavis.edu/products/cufr_43.pdf
Currently, 900 million metric tons (440-990 million tons) of carbon is stored in U.S. community forests' above-ground biomass	City of Boulder Water Conservation Office. (October, 2002). Calculating the Value of Boulder's Urban Forest. Accessed via: www.boulderutilities.net
Avoided CO2 benefits from urban forestry are greatest in inland areas where air conditioners are used throughout the summer, and coal is the primary fuel for electric power, as coal-fired plants emit twice as much CO2 per unit of energy than do other fuel sources.(McPherson and Simpson, 1999).	City of Boulder Water Conservation Office. (October, 2002). Calculating the Value of Boulder's Urban Forest. Accessed via: www.boulderutilities.net
Key to maximizing CO2 sequestration is to select tree species that are well-suited to the site.	McPherson, E.G. Simpson, J. (January 1999). Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. Accessed via: http://cufr.ucdavis.edu/products/cufr_43.pdf
Typically, CO2 released due to tree planting, maintenance activities is about 1 to 5 % of annual CO2 reductions obtained through sequestration and avoided power plant emissions. For example, Sacramento's 6 million trees required the release of 9,422 t of CO2 annually to maintain them (McPherson and Simpson, 1999).	McPherson, E.G. Simpson, J. (January 1999). Carbon Dioxide Reduction Through Urban Forestry: Guidelines for Professional and Volunteer Tree Planters. Accessed via: http://cufr.ucdavis.edu/products/cufr_43.pdf
A car burns in one minute of running time more oxygen than a mature tree can produce in a day. That same tree produces enough oxygen in one day to sustain a family of four people.	Houston/Galeveston report

ses (GHGs) are gases in the atmosphere that contribute to the formation of an insulating blanket around the Earth by trapping heat from infrared radiation. GHGs allow incoming solar radiation to
c (man-made) processes and are believed to be the main cause of global warming. The main GHG that contributes to climate change, and a cause of concern for Denver, is carbon dioxide (CO2), a
exhaust and industrial sources, HFC (hydrofluorocarbons) in refrigerants, sulfur, water vapor, (EPA, 2001)

Notes	Sources

Carbon Dioxide emissions	Trees slow global warming, which most researchers attribute to the increasing levels of greenhouse gases, especially CO2, caused by fossil fuel combustion and deforestation. Although CO2 is necessary for photosynthesis and is stored (as carbon) in biomass, the amount of CO2 currently being produced greatly exceeds the ability of the earth's vegetation to return oxygen and store carbon. An acre of trees absorbs enough CO2 in a year to equal the amount produced by driving a typical car 26,000 miles (Houston/Galveston report).	Air pollution in Denver mainly derives from motor vehicle exhaust emissions, with industrial pollution playing a minor role. Denver's air pollution levels are also exacerbated by temperature inversions resulting from Denver's geographic location. During a temperature inversion, a warm, less-dense inversion layer of air overlies colder, denser air, forming a "lid" that traps pollutants below it. In Denver the trapping effect is even more pronounced because long periods of calm weather and light winds trap pollutants against nearby mountains (Koken et al, 2003).
Carbon Monoxide	Trees absorb Carbon Monoxide in the same way they absorb CO2,	
Methane	Soil under trees emits less methane because methane production is reduced by lowering the water table, scientists at the Centre for Ecology & Hydrology Merlewood have found. Niall McNamara recorded lower methane emissions from soils under 11-year-old sessile oaks, alder and Scots pine at a longterm experimental site at the Gisburn Forest in Lancashire. Niall said, 'Soil microbes both consume and produce methane, making it difficult to quantify emissions. Although these young forest soils had a low capacity for consuming methane, soil core experiments confirmed that less methane production was taking place when the water table was lowered. So planting trees may, at first, reduce methane emissions by lowering the water table, thus reducing the contribution of methane production to net emissions.' (NERC annual report)	Difficult to quantify, few studies, however new research indicates that trees may emit between 10-30% of the methane in the atmosphere. A study by Frank Keppler of the Max Planck Institute, Germany found that living plants emit methane in the presence of air, under normal physiological conditions, not necessarily just through bacterial action in anorix environments as previously thought. Tropical plants emitted the highest amounts according to the Keppler study.
Nitrrogen Oxides	Nitrous oxide emissions and sequestration from trees is difficult to determine because scientific research is lacking, however forests can serve as natural sinks as well as sources of both methane and nitrous oxide.	Adequate research to establish accurate estimate of aggregate methane and nitrous oxide emissions and sequestration is lacking. However, when soil is cultivated, it may increase nitrous oxide emissions. Nitrous oxide gas risen by more than 15% since 1750. Each year we add 7-13 million tons into the atmosphere by using nitrogen based fertilizers, disposing of human and animal waste in sewage treatment plants, automobile exhaust, and other sources not yet identified. It is important to reduce emissions because the nitrous oxide we release today will still be trapped in the atmosphere 100 years from now. (World Book Volume 13, as cited in Hopwood and Cohen, n.d.)

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APPENDIX G
Background Research-4

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Air Pollutants can be either Primary Air Pollutants (produced from a direct process, such as car exhaust or volcanic ash) Secondary Air Pollutants (not emitted, rather form in the air or interact, such as ozone) or both. Man-Made Primary Air Pollutants include: oxides of sulfur, nitrogen, and carbon, particulate matter. Secondary Air Pollutants include: photochemical smog, ozone, nitrogen dioxide (EPA, 2001)	1) EPA. (December, 2001). Principle Air Pollutants. Accessed via: http://www.epa.nsw.gov.au/envirom/princairpol.htm 2) Koken, P., Piver, W., Ye, F., Elixhauser, A., Olsen, L., Portier, C. (2003). Temperature, Air Pollution, and hospitalization for cardiovascular diseases among elderly people in Denver. Accessed via: http://www.findarticles.com/p/articles/mi_m0CYP/is_10_111/ai_107756466
Methane is said to be up to 20 times stronger than CO2 in advancing global warming (Hasslberger, 2005)	1) NERC Annual Report. (2002-2003). Climate change. Retrieved from: http://www.nerc.ac.uk/annualreport03/science/climate.asp 2) Scientists question trees' role in global warming" (1/12/2006) Retrieved from: http://www.abc.net.au/news/newsitems/200601/s1545977.htm 3) Hasslberger, Sepp (2005, February 1). Global Warming: Methane could be far worse than carbon dioxide. Retrieved from: http://www.newmediaexplorer.org/sepp/2005/02/01/global_warming_methane_could_be_far_worse_than_carbon_dioxide.htm
	1) Energy Information Administration/Emissions of Greenhouse Gases in the United States 1995 URL: http://www.eia.doe.gov/oiaf/gg96rpt/chap7.html