ENVIRONMENTAL SERVICES
CITY OF PORTLAND
working for clean rivers

CITY OF PORTLAND BUREAU OF ENVIRONMENTAL SERVICES

Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits

FINAL

FEBRUARY 16, 2010

PREPARED BY

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Abbreviations & Acronyms

BMP	Best Management Practice
G2G	Grey to Green
BES	Bureau of Environmental Services
ESA	Endangered Species Act
EPA	Environmental Protection Agency
NPDES	National Pollutant Discharge Elimination System
TSS	Total Suspended Solids
USFS	U.S. Forest Service
PM_{10}	Particulate Matter (less than 10 micrometers in diameter)
GHG	Greenhouse Gas
CO_2	Carbon Dioxide
kWh	KiloWatt Hour
BTU	British Thermal Unit
UHI	Urban Heat Island

S E C T I O N 1

Introduction

Portland's average annual rainfall generates approximately ten billion gallons of stormwater runoff. As an alternative to traditional grey infrastructure that moves stormwater from the point of collection to a centralized treatment area, the approach of the Portland Bureau of Environmental Services (BES) is to increasingly manage stormwater where the rain falls with facilities that work like natural systems. The City of Portland (City) is a national leader in green development practices and sustainable stormwater management, and has increased its commitment to funding green infrastructure for stormwater management through the BES Grey to Green (G2G) Initiative. The purpose of the G2G Initiative is to expand the City's green infrastructure, and it includes the following elements, or Best Management Practices (BMPs): constructing ecoroofs and green streets, planting trees in urban areas, removing invasive species and revegetating, removing culverts, purchasing land in undeveloped areas, and planting in natural areas.

BES coordinates the citywide response to the federal National Pollutant Discharge Elimination System (NPDES) stormwater permit that requires the City to reduce stormwater pollution to surface water. BES also oversees other programs that address water quality and endangered species requirements of the Clean Water Act, Safe Drinking Water Act, Endangered Species Act (ESA), and state land use planning goals. By creating G2G green infrastructure, however, BES is not only reducing stormwater runoff and improving water quality and habitat, but is also providing services and benefits related to community livability, health, and energy. To capture the range of benefits provided by the G2G green infrastructure, BES started thinking in terms of ecosystem services.

Ecosystem services are commonly defined as the benefits that people derive from natural ecosystems. The Millennium Ecosystem Assessment conducted by the United Nations defined four types of ecosystem services (Millennium Ecosystem Assessment, 2010).

- Provisioning Services or the provision of food, fresh water, fuel, fiber, and other goods;
- Regulating Services such as climate, water, and disease regulation as well as pollination;
- Supporting Services such as soil formation and nutrient cycling; and
- Cultural Services such as educational, aesthetic, and cultural heritage values as well as recreation and tourism.

By restoring natural ecosystems and integrating natural areas into the urban ecosystem, BES recognizes that the G2G BMPs are providing a combination of provisioning, regulating, supporting, and cultural services. As the relationship between urban nature and ecosystem services is an emerging field of research with diverse elements, BES determined to engage a wide spectrum of local experts to identify and measure these benefits. BES contracted with ENTRIX to provide technical guidance in the benefit quantification, and with EnviroIssues to facilitate the process. This report documents the process and the findings of this effort. The remainder of this introduction describes the project background, the project purpose, the project process, the G2G BMPs, future work, and the report organization.

1.1 PROJECT BACKGROUND

In 2006, BES focused internal resources on estimating the hydrology, habitat, and water quality benefits of the seven G2G BMPs. Hydrology benefits that were identified included improved evapotranspiration, reduced stormwater flows, and increased surface infiltration and groundwater recharge. BES also quantified the habitat improvements, based on preserved stream base flows, and restored or preserved aquatic and terrestrial habitat. Water quality improvements in terms of reduced metals and total suspended solids (TSS) were also identified.

In 2009, BES began quantifying the ecosystem service benefits of its G2G BMPs. BES contracted with ENTRIX and EnviroIssues to develop an expert panel process to estimate these additional benefits generated by the BMPs. These "other benefits" are more social or economic in nature, and were initially categorized by BES into five groups: community livability, air quality, energy savings, carbon sequestration, and cost effectiveness. Tables A.1 and A.2 in Appendix A present a summary of the varied benefits provided by G2G BMPs, including a summary of BES's original estimates of hydrology, habitat, and water quality benefits. These benefits were the starting point for this project.

1.2 PROJECT PURPOSE

The purpose of this project is to provide an expert review of existing data and to quantify (to the extent possible) key ecosystem benefits associated with each G2G BMP, focusing on the "other benefits" categories that are more social and economic in nature. The project identifies categories of benefits, develops metrics (or representative indicators), and measures the relative benefit contribution of each BMP. The study is not intended to present a complete summary of benefits, but rather to identify and quantify metrics that indicate overall benefit. Recognizing that comprehensive information may not be available regarding the benefits of each BMP, the study identifies data gaps, areas of further research, and strategies to reduce uncertainty regarding benefit estimation. To the extent possible, benefits are estimated quantitatively but are also described qualitatively as necessary.

The benefits information developed in this study will supplement the hydrologic, water quality, and habitat benefits data already developed by BES. The combined benefits data will be used to assess the total benefits derived from each BMP in the G2G Initiative. The data may also be used by G2G Initiative management to compare BMPs and assess which will provide the greatest benefits relative to cost. In the larger context, BES intends that the work completed for this study may be referred to and applied throughout the City when data are needed regarding the types and magnitude of ecosystem benefits that are generated from green infrastructure projects.

1.3 EXPERT PANEL PROCESS

BES convened a diverse panel of experts representing government, academia, development, and non-profit organizations to define and quantify the "other benefits" provided by the G2G BMPs. A complete description of the expert panel process is provided in Appendix B. Table 1.1 lists the benefits categories and metrics selected by the expert panel for inclusion in this project. While these metrics do not reflect all of the benefits provided by the G2G Initiative, they capture many of the key benefits and provide a foundation for further research.

Table 1.1 Benefit Categories and Metrics

Benefit	Benefit Category	Metric
Health	Air Quality Improvement	PM_{10} Respiratory Symptoms
	Increased "Greenness"	Physical Health Mental Health
Energy and Carbon Sequestration	Energy Savings	Electricity Usage
	Greenhouse Gas Reduction	Carbon Sequestration and Emission
Community Livability	Amenity/Aesthetics Improvements	Property Values
	Community Cohesion	Social Capital Crime
	Access to Nature	Number of People affected by BMP
	Environmental Equity	Relative Share of BMPs in Minority/Low Income Neighborhoods

Based on the three types of benefits that formed the framework for this project (i.e., Health; Energy and Carbon Sequestration; and Community Livability), the panel was divided into three subgroups to examine the benefits in depth. Expert panel members were invited to participate in this project based on their backgrounds, ensuring that a broad range of benefit categories and metrics would be considered. Panel members donated their time to this project and provided invaluable perspective and expertise. Panel members are listed below by subgroup. In addition to exert panels, this project received expert review of the final report from: Dr. Kathleen Wolf (University of Washington) and Jeff Moeller (Water Environment Research Foundation).

Table 1.2 Expert Panel Members

Name	Affiliation	Subgroup
Debbie Beck	Portland State University, Green Roof Design and Testing Laboratory	Energy
Steve Fancher	City of Gresham	Energy
Allen Lee	Cadmus Group*	Energy
Tom Liptan	City of Portland, Bureau of Environmental Services	Energy
Seth Moody	Portland State University	Energy
Michael Weedall	Bonneville Power Administration	Energy
Eric Wentland	John Eric Wentland Inc.	Energy
Daniela Cargill	City of Portland, Bureau of Environmental Services	Health
Linda Dobson	City of Portland, Bureau of Environmental Services	Health
Geoffrey Donovan	US Forest Service, Pacific Northwest Research Station	Health
Patricia Huback	Department of Environmental Quality, NW Region Air Quality Program	Health
Chris Lowe	Oregon Health Sciences University, Department of Public Health and Preventative Medicine	Health
Jennifer Karps	City of Portland, Bureau of Environmental Services	Health
Monica Russell	Department of Environmental Quality, NW Region Air Quality Program	Health
Dave Kliewer	City of Portland, Bureau of Environmental Services	Health
James Allison	City of Portland, Bureau of Environmental Services	Community Livability
Bobby Cochran	Clean Water Services	Community Livability
Ryan Durocher	City of Portland, Bureau of Environmental Services	Community Livability
Paige Goganian	City of Hillsboro, Planning Department	Community Livability

Don Goldberg	Trust for Public Lands	Community Livability
Mike Houck	Urban Greenspaces Institute	Community Livability
Roberta Jortner	City of Portland, Bureau of Planning and Sustainable Development	Community Livability
Deborah Lev	City of Portland, Portland Parks	Community Livability
Noelwah Netusil	Reed College, Economics Department	Community Livability
Heather Randol	City of Portland, Bureau of Environmental Services	Community Livability
Dan Vizzini	City of Portland, Bureau of Environmental Services	Community Livability
Dennis Wilde	Gerding Edlin	Community Livability

** Danielle Kolp and Cynthia Kan of Cadmus Group worked with Allen Lee and attended the second workshop meeting to support the Energy subcommittee's presentation.

1.4 GREY TO GREEN BEST MANAGEMENT PRACTICES (BMPS)

The G2G Initiative aims to accelerate implementation of green infrastructure in Portland and is comprised of several BMPs. The benefits of these BMPs are identified and quantified in Section 2, Summary of Benefits. Brief descriptions of each G2G BMP and their associated G2G program goals are provided below.

1.4.1 Ecoroofs

Ecoroofs replace conventional roofing materials with a living, breathing vegetated roof system. An ecoroof consists of a layer of vegetation over a growing medium on top of a waterproof membrane. Ecoroofs significantly decrease stormwater runoff by detaining and evaporating stormwater on site. In addition, ecoroofs save energy, filter pollutants, cool urban heat islands, provide habitat, create green spaces, improve community livability, and provide educational opportunities.

There are currently 172 ecoroofs in Portland, totaling nearly ten acres. The five-year G2G goal is to add 43 acres of ecoroofs. In the fall of 2008, BES began an incentive program to fund $5 per square foot of new ecoroof construction. Education and outreach to developers and private citizens are also underway to promote ecoroof development and construction throughout the City.

1.4.2 Green Streets

Green streets are vegetated curb extensions, streetside planters, or infiltration basins (rain gardens) that collect stormwater runoff from streets. Green streets reduce stormwater flow to sewers, reduce pollutants and limit erosion in urban streams, provide wildlife habitat and neighborhood green spaces, and refresh groundwater supplies.

The five-year G2G goal is to construct 920 green street facilities, emphasizing partnerships with other city bureaus and agencies such as the Portland Water Bureau, the Portland Bureau of Transportation, and the Portland Development Commission. As of fall 2009, there are approximately 700 green street facilities in Portland that cumulatively manage an estimated 48 million gallons of stormwater runoff a year. Of the 920 planned facilities, an estimated 573 (62 percent) will be located in the combined sewer area.

1.4.3 Trees

Trees protect watershed health by absorbing rain (which restores hydrology) and preventing erosion (which protects water quality and habitat). In this way, trees are a vital, long-term, and low-cost component of Portland's green infrastructure for managing stormwater. Trees also clean the air, create restorative spaces, and provide cooling shade and wildlife habitat. Street trees can improve property values and slow traffic, making streets safer for pedestrians, bike riders, and motorists.

The five-year G2G goal is to plant 33,000 yard trees and 50,000 street trees. Much of the tree planting BMP is a collaborative effort with the Portland non-profit organization, Friends of Trees. BES is also sponsoring a rebate program to encourage Portland residents to plant trees on their property.

1.4.4 Invasive Removal and Revegetation

Invasive plants have an impact on water quality, biodiversity, fish and wildlife habitat, tree cover, and fire risk and costs. Increasing efforts to prevent and control invasions in high quality natural areas is the most cost-effective and ecologically successful approach. Removing invasive vegetation and restoring native plants reduces stormwater volume, filters stormwater pollutants, provides habitat diversity, and cools the air, pavement, and streams. The five-year G2G goal is to remove invasive plants from 1,900 acres of city parks and control invasive plants on an additional 840 acres citywide.

1.4.5 Culvert Removal

Culverts contribute to flooding and erosion and also can block fish passage, which reduces the amount of habitat available to ESA-listed species. The G2G culvert removal BMP focuses on opening up the Crystal Springs Creek system from headwaters to mouth by removing/replacing eight culverts (five year G2G goal). Associated streambed restoration projects are planned through partnerships with Reed College, Portland Parks and Recreation, and other organizations.

1.4.6 Land Purchase

Development on steep slopes and drainage ways can cause landslides and erosion, increase flooding problems, and harm water quality and habitat. Public acquisition of natural areas protects these areas from development and preserves watershed and floodplain functions. BES is working with Portland Parks and Recreation, Metro, Trust for Public Lands, and Three Rivers Land Conservancy to identify high priority acquisition areas that contain sensitive natural communities, protect water quality, and expand habitat connectivity. The G2G five-year goal is to purchase and protect 419 acres of high priority natural areas.

1.4.7 Planting in Natural Areas

While the invasive removal and revegetation BMP (Section 1.4.4) focuses efforts on high quality natural areas and specific invasive species, this program manages highly degraded sites by removing all invasive species and establishing native trees, shrubs, grasses, and wildflowers. Creating healthy native ecosystems helps reduce stormwater volume, filter pollutants, provide cooling shade for streams, and provide diverse habitat to support native wildlife. Since 1996, the City and community partners have restored more than 2,000 acres of upland area and over 500,000 feet of stream bank. The five-year G2G goal is to restore 70 acres of habitat per year for a total of 350 acres.

1.5 CONTEXT OF FUTURE WORK

New and ongoing research continues to provide data regarding ecosystem services and the social and economic benefits provided by green infrastructure. BES will continue to review such data and incorporate relevant information into decision-making. BES will work to assign monetary values to as many of the benefits as possible to provide a common unit for comparing the costs and benefits of G2G BMPs. The goal of this report was to identify and quantify the social benefits of G2G programs, and to lay the foundation for valuation of these benefits. Additional work may also focus on the economic value to businesses.

Results will be shared with City Council and other City Bureaus and interested parties, and will inform ongoing efforts to spend ratepayer money wisely, address climate change, and manage growth.

1.6 REPORT ORGANIZATION

This report has five additional sections. Section 2 summarizes the findings, while Sections 3, 4, and 5 provide additional description and supporting documentation for the benefits identification and measurement. Section 6 discusses recommendations for additional research and activities related to quantifying G2G benefits, as well as the next steps for disseminating the results of this project and incorporating the information into BES decision-making. A reference section provides references cited in the report as well as additional references that may be useful in future research efforts. Finally, the appendices include information regarding previous benefits quantification work conducted by BES, details regarding the expert panel process, and the notes from each expert panel workshop and each subgroup meeting.

SECTION 2

Summary of Benefits

This section provides a summary of the benefits estimated through the expert panel process and follow-up work conducted by ENTRIX and BES. The purpose of this project is to define and estimate the magnitude of "other benefits" for the G2G BMPs. Table 2.1 summarizes research findings on the other benefits relating to health, community livability, and energy. The table columns are the final benefits categories as revised by the expert panel, while the rows are the seven G2G BMPs. The metrics chosen by the expert panel are also presented in a row of italics below the benefits category titles. Table 2.2 defines and provides brief descriptions of the metrics.

The benefit estimates in Table 2.1 are based on currently available data and research, and are intended to be updated as more information becomes available. The data are both qualitative and quantitative; some benefits such as energy savings were more easily quantified than other benefits, such as those related to community cohesion or mental health. The benefits estimated are not intended to be a comprehensive quantification of all G2G benefits, but are rather intended to provide a representative measurement (through the use of metrics) of the types and magnitude of benefits of the G2G Initiative.

Benefit estimates are organized into three types in Table 2.1: BMPs that have a known positive effect are shaded dark green, BMPs with a potentially positive effect are shaded light green, and BMPs with either an unknown effect or are non applicable (N/A) to a particular type of benefit are left unshaded. Finally, it should be noted that the level of certainty regarding the benefit information also varies across estimates.

Table 2.1 Health, Energy, and Livability Benefits of G2G BMPs.

	"Other Benefits" Categories							
	Health		Energy		Community Livability			
G2G BMP	Air Quality Improvement	Increased Greenness	Energy Savings	Greenhouse Gas Reduction	Amenity/Aesthetics Improvement	Community Cohesion	Environmental Equity	Access to Nature
Metric:	*PM_{10} Removal*	*Enhanced Mental and Physical Health*	*Electricity Usage*	*CO2 Reduced Emissions/Sequestration*	*Property Values*	*Social Capital and Crime*	*Relative Share of BMPs in Minority / Low Income Neighborhoods*	*Number of People Affected by BMP*
Ecoroofs	7.7 lbs / acre / year	Associated with improved physical and mental health	8,270+ kWh/Acre	7.1 metric tonnes / acre / year	Possible positive effect	Possible positive social capital effect, no known effect on crime	Possible positive effect, depends on BMP location	Magnitude is dependent on the number of people with views of or access to the ecoroofs.
Green Streets	0.04 lbs / facility / year	Associated with improved physical and mental health	155+ kWh/facility	0.3 metric tonnes / facility / year	Positive, 3% to 5% increase in home values experienced due to combined Greenstreets + Swales + Culvert Removal	Increase social capital, decrease crime	Possible positive effect, depends on BMP location	2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas
Trees: Yard	0.2 lbs / tree / year	Associated with improved physical and mental health	11+ kWh/tree	0.1 metric tonnes / tree / year	Likely positive effect	Potentially increase social capital, mixed effect on crime	Possible positive effect, depends on BMP location	Positive, but relatively smaller effect
Trees: Street	0.2 lbs / tree / year	Associated with improved physical and mental health	1.4+ kWh/tree	0.1 metric tonnes / tree / year	Approximate increased home value (including to surrounding homes) of $14,500 per tree	Increase social capital, decrease crime	Possible positive effect, depends on BMP location	2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas
Invasive Removal/ Revegetation	N/A	Possible positive effect	Possible positive effect	Uncertain effect	Uncertain effect	N/A	Possible positive effect, depends on BMP location	Uncertain effect
Culvert Removal	N/A	Possible positive effect	N/A	N/A	Positive, 3% to 5% increase in home values experienced due to combined Greenstreets + Swales + Culvert Removal	N/A	Possible positive effect, depends on BMP location	Uncertain effect
Land Purchase	23.2 lbs / acre / year	Possible positive effect	Possible positive effect	Possible positive effect	Positive, 14% increased home value for homes within 800 – 1,000 feet of natural park.	Depends on BMP siting, possible positive effect	Possible positive effect, depends on BMP location	Possible positive effect, depends on BMP location
Planting Natural Areas	20.9 lbs / acre / year	Possible positive effect.	Positive effect	7.0 metric tonnes / year / acre	Positive, 3- 13% increases in property values for stream restoration efforts.	N/A	Possible positive effect, depends on BMP location	Possible positive effect, depends on BMP location

Table 2.2 Benefit Metrics

Benefits Category	Metric	Definition / Description
Air Quality Improvement	PM_{10}	PM_{10} is particulate matter that is less than 10 micrometers in diameter. This type of particulate matter is associated with adverse impacts on respiratory health. Vegetation reduces the amount of PM_{10} in the air.
Increased Greenness	Mental and Physical Health	Increased vegetation, or general greenness, is associated with positive effects on physical and mental health. Physical health effects may include increased physical activity and reduced obesity, stress, and longer life expectancy. Mental health effects may include decreased depression, a more positive outlook, increased focus and reduced attention deficit disorder (ADD) symptoms.
Energy Savings	Electricity Usage	Electricity is used in the City to pump stormwater runoff and to heat and cool buildings. The G2G BMPs are expected to reduce the electricity usage of these activities.
Greenhouse Gases	CO_2 Emissions/ Sequestration	Carbon Dioxide (CO_2) and other greenhouse gases are generated when fossil fuels are burned to generate electricity. Emission of these gases is reduced with reduced electricity usage. Additionally, vegetation and soils in natural areas sequester carbon, reducing the amount of CO_2 in the atmosphere.
Amenity/Aesthetics	Property Values	Property values are determined not only by the value of the property itself, but also the attractiveness of surrounding amenities and aesthetics. Property values can be used to measure the enhanced aesthetics/ amenities due to increased levels of vegetation and restored natural areas.
Community Cohesion	Social Capital and Crime	Social capital refers to positive social interaction and supportive social networks that generate individual and public benefits. Increased vegetation and green spaces is associated with increased social capital, as they encourage the use of outdoor spaces and neighborly interaction. Vegetation is also associated with reduced crime rates, potentially due to increased social capital or potentially due to a direct effect on behavior.
Environmental Equity	Relative Share of BMPs in Minority / Low Income Neighborhoods	Several BMPs may be implemented in neighborhoods, and will enhance the level of greenness in those neighborhoods. This metric measures whether the distribution of BMPs in neighborhoods is equitable across minority/low-income and other neighborhoods.
Access to Nature	Number of People Affected by BMP	The benefits of increased vegetation and/or natural areas depend on the number of people who view or access the area. This metric aims to measure the number of people who will view, walk past, or access each type of BMP.

Sections 3, 4, and 5 provide detailed descriptions of the benefit categories and metrics used to quantify the Health, Energy, and Community Livability benefits associated with the G2G BMPs. For each benefit category, data sources and methodology are described, as well as benefit estimation and certainty level. The applicability of the metric and an estimate of benefit are discussed for each G2G BMP.

SECTION 3

Health

There are many positive relationships between human health and green infrastructure. Natural areas and increased levels of vegetation can directly improve health by improving air quality and reducing air quality-related illnesses. Additionally, by increasing the level of greenery in the urban environment, green infrastructure can indirectly enhance both physical health (by increasing an individual's propensity to walk and exercise outside) and mental health (by improving the visual quality of the environment and thereby reducing stress and mental fatigue). There is evidence that some mental health effects can also result in positive impacts on physical health, and vice versa, which indicates not only that there is overlap in effects but also that determining causal mechanisms is complicated. Despite the difficulty in determining cause and effect relationships with some health benefits, the health subgroup focused on air quality, mental health, and physical health benefits as the three primary health benefits to Portland residents that may result from G2G BMPs.

While numerous studies have documented the positive health effects of green infrastructure, the quantitative relationship between incremental increases in vegetation and green spaces and effects on physical and mental health are difficult to estimate. Specifically, identifying and estimating the individual effect on health of each G2G BMP is difficult given the available literature and the relative size of the G2G BMPs in the context of the City's overall level of vegetation and green infrastructure. As a result, many of the benefits described in this chapter provide a more general sense of the magnitude and type of health benefits that may be derived from G2G, rather than specific, quantitative estimates of the benefits of each BMP. Quantitative estimates of the benefits of each G2G BMP are limited to the air quality benefits provided by increased levels of vegetation.

To organize the discussion and estimation of health benefits, the health subgroup developed the benefit categories and associated metrics summarized in Table 3.1 below.

Table 3.1 Health Benefit Categories and Metrics

Benefit Category	Metric	Unit
Air Quality Improvement	PM_{10} Respiratory Symptoms	Pounds/ Year % Change Presence Respiratory Symptoms
Increased Greenness	Physical Health, Mental Health	Qualitative

3.1 AIR QUALITY HEALTH EFFECTS

Trees and other vegetation improve ambient air quality by removing air pollutants that can negatively affect health. Specifically, vegetation absorbs and intercepts such potentially harmful pollutants as nitrogen dioxide, particulate matter, carbon monoxide, and sulfur dioxide (Nowak, 2006). These pollutants are removed by vegetation through gaseous uptake, as well as through physical deposition of particulates on vegetation surfaces. Reduced ambient air concentrations of these pollutants improve health by reducing incidents or severity of respiratory illness such as asthma, bronchitis, lung disease, and respiratory infections (Air Now, 2009).

While vegetation may also release air pollutants that are detrimental to human health, these effects are expected to be minor and were not estimated for this study. Trees and shrubs release volatile organic compounds (VOCs) which can contribute to the formation of ozone, but this effect may be offset by the effect of vegetation (particularly trees) in reducing ambient air temperature and reducing building energy consumption (thereby reducing ozone creation) (Nowak, 2006). Some vegetation may also release pollen that increases allergic reactions. This effect is assumed to be minimal, however, as it is not expected that the vegetation planted in the G2G Initiative will measurably increase pollen levels. Furthermore, according to the National Institute of Environmental Health Sciences, most vegetation types do not cause allergies. For example, of the 50,000 different types of trees in North America, less than 100 have been shown to cause allergies, while a similarly small percentage of the 1,200 species of grass that grow in North America cause allergies (NIEHS, 2009). It is recognized that there could be localized concentrations of pollen or allergies that result from increased vegetation; these effects are not estimated but may affect certain individuals.

To estimate the health benefits of increased air quality associated with G2G BMPs, the health subgroup chose as a representative metric the concentration of particulate matter less than 10 micrometers in diameter (PM_{10}). PM_{10} was chosen as the indicator of air quality because it has measurable and well quantified impacts on human health. Particles of this size are small enough that they can get into the lungs, potentially causing serious health problems. Additionally, PM_{10} was chosen as there are data available on ambient concentrations in Portland, and vegetation in Portland has the ability to remove it from the air. The level of health benefits in terms of incidents of respiratory illness associated with reduced PM_{10} levels were also estimated for all existing vegetation in the City. The total effect on Portland air quality from increased vegetation due to the G2G Initiative is expected to have a minor effect on overall respiratory illness and was not estimated. Air quality benefits, in terms of reduced PM_{10} levels, were estimated for ecoroofs, green streets, trees, and planting in natural areas. Preservation of PM_{10} removal through purchase of lands in natural areas is also estimated.

3.1.1 Data Sources and Methodology

Air quality benefits were estimated based on models of PM_{10} removal by trees and shrubs. These data were extrapolated to estimate benefits of ecoroofs, green streets, and natural plantings. To estimate health benefits, the data on quantity of PM_{10} removal were converted to concentration of PM_{10}, and then assessed using a concentration response function developed by the Environmental Protection Agency (EPA) (EPA, 1999).

Estimates of air quality benefits from vegetation were drawn from US Forest Service (USFS) modeling of pollution removal in Portland using the Urban Forest Effects (UFORE) model. Based on a local inventory of trees and shrubs as well as local data on meteorological conditions and pollution concentration levels, the UFORE model estimates the air pollution removed by trees and shrubs in Portland. The lead developer of this model, Dr. David Nowak at the USFS Northern Research Station, provided estimates of air pollution removal by all trees and shrubs in Portland as well as the air pollution removal per square meter of canopy (pers.comm. Nowak, 2009). Nowak's estimates are based on air pollution concentration and canopy cover levels in the City of Portland in 2000. Table 3.2 presents the data that Nowak and his colleagues provided for air pollution removal by Portland trees and shrubs. Although PM_{10} concentration is the metric chosen for this study, data provided by Nowak are for five pollutants known to adversely affect health (carbon monoxide – CO, nitrogen dioxide –NO_2, ozone –O_3, PM_{10}, and sulfur dioxide –SO_2). The data for both monthly and annual pollutant removal for each pollutant in metric tones (approximately 2,200 pounds) are presented below in Table 3.2, while the average pollutant removed in grams per square meter of tree or shrub canopy are presented in Table 3.3. It was assumed in this analysis that the average air pollutant removal per square meter of tree canopy from the year 2000 (as provided in Table 3.3) is a good indicator of future pollution absorption (e.g. that future pollution removal per canopy area will not vary significantly).

Table 3.2 Removal of Selected Air Pollutants by All Trees/Shrubs in Portland

	Pollutant Removal (Metric Tonnes)				
Month	CO	NO_2	O_3	PM10	SO_2
January	0.2		1.9	8.6	
February	0.2		2.7	11.3	0.7
March	2.7		16.4	18.6	2.9
April	6.3		50.3	27.3	5.0
May	4.5	13.4	57.5	22.9	6.9
June	5.6	17.6	57.9	25.5	13.2
July	5.8	15.5	59.0	32.2	9.0
August	7.3	20.1	59.2	30.2	13.0
September	6.6	16.7	31.2	29.5	10.0
October	4.1		12.9	26.8	60.2
November	0.3		1.8	13.9	1.2
December	0.2		1.1	12.2	1.0
Annual Pollutant Removal in City	43.8	83.2	351.9	258.9	123.1

Table 3.3 Annual Removal of Selected Pollutants in Portland Per Square Meter of Canopy

Pollutant	Grams / Square Meter of Canopy / Year
CO	0.5
NO2	0.9
O3	3.6
PM10	2.6
SO2	0.7

To estimate air pollution removal per tree, data were gathered from the Portland 2007 Canopy Report on canopy cover per tree. The Canopy Report notes that there are 236,000 street trees, and that the canopy cover of these trees is 8,403,246 square meters (Portland Parks and Recreation, 2007). This indicates that existing street trees have an average canopy size per tree of 36 square meters. The street trees in the Canopy Report represent a diverse range of trees from newly planted to mature, and are nearly evenly divided between small, medium, and large trees. This suggests that the average size of a G2G tree over the course of the project life may be similar to those measured in the Canopy Report.

To estimate health benefits of reduced PM_{10} levels, it is necessary to convert the total volume of PM_{10} removed to a change in ambient concentration. Data on 2005 PM_{10} air pollution emissions and ambient concentrations are from the Oregon Department of Environmental Quality (DEQ). The data to estimate health quality benefits of reduced ambient concentrations of PM_{10} are from the EPA report, "The Benefits and Costs of the Clean Air Act, 1990 to 2010" (EPA, 1999). Health benefits are reported as avoided incidents of adverse health effects. The relationship between adverse health effects and each pollutant is quantitatively defined by concentration-response (C-R) functions. For example, the C-R function used in this study to estimate representative health effects of PM_{10} was the function quantifying the relationship between presence of respiratory symptoms and changes in ambient concentrations of PM_{10}. This function is:

*Percent change in respiratory symptoms = 0.000461 * Change in Daily Average PM_{10}Concentrations * Population between 16 and 64 years of age.*

3.1.2 Benefit Estimation and Certainty Level

To provide perspective on the air quality-related health benefits of the G2G BMPs, the benefits were estimated first for all tree and shrub vegetation in Portland. As presented in Table 3.2 above, the total PM_{10} removed by all tree and shrub vegetation in Portland is estimated at approximately 285 tons. This pollution removal is estimated to result in reduced concentrations of PM_{10} by approximately 1/3 of a microgram per cubic meter (1/3 microgram/m^3). This estimate is based on DEQ monitoring data from two Multnomah County sites in 2005 indicating that average PM_{10} concentrations were 21 microgram/m^3 (17 microgram/m^3 at SE Lafayette and 24 microgram/m^3 at Transcon) (ODEQ, 2005). Total emissions data from 2005 for Multnomah County were estimated at 15,974 tons. This roughly suggests that concentration of PM_{10} increases by approximately 1 microgram/m^3 for every 761 tons of PM_{10} emissions. Using this approximate calculation, the estimated 285.4 tons removed by all tree and shrub vegetation in Portland results in a reduction in PM_{10} concentrations of 0.375 microgram/m^3, or roughly 1/3 of a microgram/m^3. It is important to note that this approach makes several simplifying assumptions, which significantly reduce certainty in the estimate.

The health benefit of reducing PM_{10} concentrations by 1/3 microgram/m^3 was estimated using the EPA C-R function for percent change in presence of respiratory symptoms. Based on the equation presented in the previous section, and a population in Portland of 378,340 people between the ages of 18 and 64, the incidence of respiratory illness in Portland is estimated to decrease by nearly 18 percent (0.000461 * 0.375 microgram/m^3 / 365 days* 378,340 people). Using the population of Multnomah County, which may be a more accurate population to use in this equation since the data on concentration levels are from the entire County and air quality effects may range that far, the reduction in respiratory symptoms may be nearly 23 percent.

This data were then applied to the G2G BMPs. For trees, the data estimated by the UFORE model were directly applied without any adjustments (which likely results in an overestimate because the UFORE model of canopy cover also included shrubs below the tree canopy). However, for the other BMPs that would increase vegetation that is more shrub or grasslike, the estimate from the UFORE model was adjusted downward to account for the fact that the leaf area index (LAI), or layers of leaves within an area of canopy is lower on ecoroofs or green streets than in a tree canopy, as well as other differences such as species type which affect pollution removal rates. The 2008 study of ecoroof design indicates that a base LAI for ecoroofs in Portland is two leaf layers (PSU, 2008). The Portland UFORE model assumes that LAI in Portland is, on average, six leaf layers. So based on these estimates of LAI, the results from the UFORE model were divided by three to account for potential differences influencing the ability of greenstreets and ecoroofs to remove pollution compared to trees. This assumes that grasses remove pollutants at similar rates as trees. Due to this approximation, there is high uncertainty in the estimates for all non-tree BMPs. The estimate for each BMP is summarized in Table 3.4 and then discussed below.

Table 3.4 Summary of Air Quality Benefits by BMP

G2G BMP	Applicable	Relationship (PM 10 Removal)	Comment
Ecoroofs	Yes	7.7 lbs / acre / year	Results are less certain as they are extrapolated from a different vegetation type.
Green streets/swales	Yes	0.04 lbs / facility / year	Results are less certain as they are extrapolated from a different vegetation type.
Trees	Yes	0.2 lbs / tree / year	Results are relatively more certain for this BMP as the data are based on tree and shrub vegetation.
Invasives removal / revegetation	Uncertain		Could be applicable if BMP increases total vegetation cover and leaf area.
Culvert Removal	No		Culvert removal itself does not result in changes in vegetation.
Land Purchase	Yes	23.2 lbs / acre / year	Benefits are preserved benefits based on an area with full canopy cover.
Planting in natural areas	Yes	20.9 lbs / acre / year	Benefits are preserved benefits based on an area with nearly full canopy cover.

3.1.2.1 Ecoroofs

The UFORE data from the USFS indicate that for every square meter of tree and shrub canopy in Portland, 2.6 grams of PM_{10} is removed from the air annually. As noted above, the effect of a square meter of ecoroof is expected to be less than a square meter of tree canopy. Using LAI as a proxy for the relative effect of ecoroof vegetation area compared to tree canopy area for PM_{10} removal, we divide the 2.6 grams of PM_{10} by three (since LAI for ecoroofs is estimated at two and the LAI for Portland canopy is estimated at six) to estimate pollution removal of 0.9 grams per square meter of ecoroof. This estimate indicates that an **acre of ecoroof may remove approximately 7.7 pounds of PM_{10} per year.** The target of 43 acres of green roofs would thus remove approximately 333 pounds of PM_{10} per year.

Although there is significant uncertainty in the applicability of this adjustment to estimate air quality effects of ecoroofs, the alternative data were judged to be less reliable. While there are studies on the effect of air quality of ecoroofs, these studies were not utilized as the data were either from very different locations (and therefore likely not applicable to Portland) or were not verifiable. Studies that were evaluated include one conducted on air quality benefits of ecoroofs conducted in Toronto, Canada using the UFORE model (Currie, 2005). This study found that 109.386 hectares of grass ecoroofs would result in a total pollution reduction of 2.17 milligrams of PM_{10}. This translates to just 0.6 grams per acre, which is several orders of magnitude less than the estimate of PM_{10} removal estimated by the UFORE model for trees and shrubs in Portland. Variation in climate, leaf area index (vertical layers of leaves within canopy cover), pollution levels, and relative ability of grasses to absorb PM_{10} may account for the large difference in results.

An often cited study for air quality benefits of ecoroofs is a report by Acks in 2003, but the original research papers supporting these findings were not cited and the results seemed high (Acks, 2003). The Acks study used an estimate of 0.44 pounds of airborne particulate matter (including particulates larger than PM10) removed per square meter of ecoroof (or 195 grams per square meter). Even adjusted downwards by 55 percent to account for the proportion of total particulate matter that is PM_{10}, this estimate is over forty times greater than the UFORE model results for trees and shrub canopy. The origin of this study result is also not clear. The Acks study cited a green roof industry association website (greenroofs.org), which currently states that every square meter of ecoroof removes 4.4 pounds of airborne particulate matter (a ten-fold increase over the Acks data). As the website does not cite the source of this finding, these data were not utilized in this report.

3.1.2.2 Green Streets

Although green streets are planted in a mixture of tree, shrub, and grass vegetation, the same figure (as used for ecoroofs) of 0.7 grams per square meter annually is used to estimate PM10 removal for green streets. The average green street facility is sized at approximately 250 square feet, or 23.2 square meters. Assuming each square meter removes 0.9 grams of PM_{10} each year, an estimated **20.2 grams (or 0.04 pounds) will be removed by each green street facility annually.** All 920 facilities would remove an estimated 40.8 pounds of PM_{10} annually.

3.1.2.3 Trees

The UFORE model results from the USFS were the most directly applicable for the trees to be planted in the G2G Initiative. As described above in Section 3.1.1, the canopy size of an average Portland street tree (based on all existing street trees, young and old) is approximately 36 square meters. Combining this data with the estimated removal of 2.6 grams of PM_{10} per square meter of canopy annually, and assuming yard trees are approximately the same size as street trees, indicates that on average across the project life, **each street tree and yard tree will remove approximately 92 grams (0.2 pounds) of PM_{10} per year**. The target of 83,000 total trees to be planted will thus result in the removal of approximately 8.5 tons of PM_{10} per year.

3.1.2.4 Culvert Removal

Although revegetation projects are often associated with culvert removal, the culvert removal BMP alone does not have an effect on vegetation levels and thus is not estimated to have an air quality impact. There may be maintenance emissions associated with project removal and construction, but these are considered minor as most projects require only a limited time period (and thus limited travel trips to the site) for implementation.

3.1.2.5 Invasive Removal/Revegetation

Removal of invasives and revegetating with native species has an unknown net effect on the total amount of vegetation. Therefore, no air quality impacts were estimated for this BMP. However, if it increases total vegetation cover and leaf area, invasive removal/revegetation could decrease PM_{10} levels.

3.1.2.6 Land Purchases

The vegetation type in areas targeted for land purchase is often temperate forest, but may also be wetland, riparian, or prairie habitats. To simplify, this analysis assumes that most land purchases will be forested, and that the average air pollution reduction benefits from vegetation in these areas is, on average, equivalent to the air pollution benefits from areas in the City with canopy cover. The analysis therefore applies the UFORE estimate of 2.6 grams of PM_{10} removal per square meter of canopy cover to the areas slated for purchase to estimate their existing air pollution removal benefit. Based on this level of pollution removal, an estimated **23.2 pounds of PM_{10} removal is being preserved by each acre of land purchases**. Purchase of the targeted 419 acres will preserve an estimated 9,724 pounds (4.9 tons) of PM_{10} removal annually.

3.1.2.7 Planting in Natural Areas

The target for this BMP is to plant 350 acres in native tree, shrub, and wildflower vegetation, including 32,000 trees. Two methods were utilized to estimate PM_{10} benefits per acre: one based on the canopy cover expected to result from 32,000 trees, and based on canopy cover on all 350 acres. The two methods provide similar findings. First, using the data estimated for trees above, each **tree will remove approximately 92**

grams (0.2 pounds) of PM_{10} per year. Planting 32,000 trees will provide an estimated 6,517 pounds of PM_{10} removal per acre, or an average of 18.3 pounds of PM_{10} removal per each of the 350 acres. This compares to the 23.2 pounds of PM_{10} removal estimated above for each acre of forested natural area land. **Taking an average of these two methods provides an estimate of PM_{10} removal of 20.9 pounds per acre annually.** For all 350 acres, the PM_{10} is estimated to average 7,320 pounds of PM10 removal annually.

3.2 GREENNESS AND GENERAL PHYSICAL HEALTH

Greenness in the form of trees, vegetation, and green spaces (such as those provided in many of the G2G BMPs) has been linked to increased physical health. Greenness includes “green spaces” that have well-defined boundaries that don’t contain residential, commercial, industrial structures or vehicular access or “green areas” which are within the street grid and are landscape design features such as street trees, bioswales, ecoroofs, or other vegetated small areas integrated into the built environment. One causal mechanism between increased greenness and physical health is that greenness may increase walking and other forms of outdoor exercise. It is hypothesized that greenness enhances the attractiveness of and access to outdoor spaces, which in turn fosters physical activity and better health. Other studies have found other potential causal mechanisms in which greenness can increase physical health, such as increased social ties and recreation opportunity. As few quantitative studies linking greenness and physical activity have been conducted, this section provides a qualitative discussion of the potential benefits on physical health of greenness.

3.2.1 Data Sources

Most of the data available on the relationship between greenness and physical health originate from northern European countries. Research has been done subjectively using questionnaires to self-report perceptions about the environment as well as objectively through GIS-based analysis of environmental attributes. While Portland’s socio-economic and cultural environments differ from northern Europe, the information in the following articles provides useful insight about how urban greenness and associated amenities along with perceptions about the environment may play a role in increasing physical health.

Several studies link increased greenness with increased physical activity. In particular, it appears that there may be a relationship between an individual’s physical activities and perceptions about environmental attributes. For example, in a study comparing coastal versus non-coastal locations and perceived quality of environmental attributes, neighborhood walking increased where there were positive perceptions about convenience, environmental aesthetics, and access (Humpel, 2004). Similarly, a study conducted by the Netherlands Organization for Applied Scientific Research found that people perceived streets as more attractive for walking if there were a lack of litter, scenic value, and the presence of activity or other people along the street (Borst, 2008). Thus, if greenness in an urban area enhances scenic value, then the attractiveness of walking or other physical activity outside may increase (Nielsen, 2007). Additionally, several studies in the literature link physical activity with proximity to green spaces that provide recreational opportunities (Neuvonen, 2007), (Wendel-Vos, 2004). However, it is unclear if the effects on physical activity found in these studies are due to the recreation amenities (such as bike paths or parks), or due to the presence of greenness, or both.

In addition to increased physical activity, greenness has been linked to other indicators of general health. The following positive health effects have been found to be associated with greenness:

- Lower Body Mass Index A study of American children indicates a correlation between greenness and a lower Body Mass Index (BMI), which may be due to increased physical activity or time spent outdoors (Bell, 2008).

- Reduced Mortality Greener environments can also reduce mortality rates for populations that would normally have higher mortality rates due to socioeconomic factors such as income and available health services (Mitchell, 2008). Physical activity could be the causal mechanism, but its role is not firmly established in these studies.
- Less Stress and Obesity A Danish study found that access to a garden or short distances to green spaces from a place of residence are associated with less stress and a lower likelihood of obesity, but that the health benefit did not increase with increased visitation of the green space. The study authors suggest that the findings may indicate that areas with shorter distances to green spaces may have other neighborhood characteristics that increase physical health, or that are more conducive to outdoor activities and "healthy modes of travel."
- Increased Perceived Health A Dutch study concluded that green space increased perceived health and resulted in fewer complaints like depression, diabetes, and chronic obstructive pulmonary disease (COPD). This study determined that the relation between green space and perceived health can be explained by increased social contacts, not increased physical activity. People with more green space in their living environment feel less lonely and less often experience a shortage of social support, which appears to correspond with better perceptions of physical health.

  While all of the previous studies found a positive association between physical health and greenness, it should be noted that one study that measured greenness quantitatively (usually using spatial vegetation data) and compared it to surveys of population health found no consistent patterns or correlation (Hillsdon, 2006). The difficulty in defining, measuring, and mapping quality urban green spaces is a challenge to quantitatively establishing a connection.

3.2.2 Benefit Estimation and Certainty Level

The literature reviewed indicates that greenness may be correlated with enhanced real and perceived physical health. However, relatively few studies have been able to demonstrate a clear, quantitative relationship between greenness and physical health as there are numerous confounding factors. These factors make it difficult to separate the effects of greenness which would be most applicable to the G2G BMPs. However, overall the literature indicates that greenness alone, as well as in conjunction with other activity-promoting amenities, is associated with enhanced overall physical health. Table 3.5 summarizes the expected benefits of green areas.

Table 3.5 Summary of Physical Activity Benefits by BMP

G2G BMP	Applicable	Relationship	Comment
Ecoroofs	Yes	Increase physical health	Ecoroofs increase vegetation that may increase walking and other positive health effects.
Green streets/swales	Yes	Increase physical health	Include trees and increased vegetation that may promote physical activity and physical health
Trees	Yes	Increase physical health	Street trees that increase perceived greenness may promote physical activity and physical health
Invasives removal / revegetation	Uncertain		Could be applicable if trees and vegetation increase perceived greenness and green space is accessible.
Culvert Removal	Uncertain		Could be applicable if culvert is part of a larger, publicly accessible restoration site that increases perceived greenness of neighborhood
Land Purchase	Uncertain		Could be applicable if the purchase would result in creation of a new park or usable green space within a neighborhood or within viewing distance of walkable streets.
Planting in natural areas	Uncertain		Could be applicable if trees and vegetation increase perceived greenness and green space is accessible.

3.3 MENTAL AND EMOTIONAL HEALTH EFFECTS

Social scientists have recently begun investigating how parks, trees, and green spaces affect our everyday moods and emotional health. The current state of the science makes quantitative, causal-relationship conclusions difficult because nearly all the literature has focused on *associations* found between greenness and mental health indicators, self reported (rather than objective, physiological) measures of mental health, and studies that included other, potentially confounding factors. However, the research indicates strong associations between greenness and mental health.

3.3.1 Data Sources

There are studies documenting that increased levels of greenness are associated with the following types of mental health benefits:

- Stress Reduction and Restorative Effects Significant relationships have been found between the use of urban open spaces and experiences of stress. Other research has shown that time in natural settings can help mental fatigue recovery and improve one's capacity to concentrate (Kaplan, 1995).
- Coping with Poverty Taking possible confounding variables into account, residents living in buildings with nearby trees assessed their issues as less severe and more solvable than counterparts living in less green surroundings (Kuo, 2001a).
- Reduced Domestic Violence: For populations with relatively high rates of aggression, reduced mental fatigue associated with proximity to greenness can result in reduced instances of aggression and violence. These effects come from increased ability to focus provided by nearby nature (Kuo, 2001c).
- Attention Deficit Disorder Symptom Management Recent studies have indicated that greenness may reduce Attention Deficit Disorders (ADD). Children who played in greener setting showed less severe ADD symptoms (Faber, 2001).
- Worker Well-Being Other studies have found that mental well-being and physical health both benefit from increased levels of greenness. Desk workers surveyed about their rate of illness and level of job satisfaction claimed 23 percent fewer more incidents of illness in the prior six months if they had a view of nature from their desks. Desk workers with a view reported: 1) their job more challenging, 2) less frustration about tasks and generally more patience, 3) greater enthusiasm for the job, 4) feelings of higher life satisfaction, and 5) better health (Wolf, 2008), (Kaplan, 1989).

Greenness combined with opportunities for social interaction may be particularly effective in improving mental health. An Australian study indicates that while recreational walking may explain the relationship between greenness and physical health, recreational walking *and* social cohesion together can significantly improve mental health (Sugiyama, 2008). It appears that walkable options that also provide opportunities for social cohesion can result in an increased mental health benefit.

3.3.2 Benefit Estimation and Certainty Level

In summary, greenness alone is associated with reducing violence, ADD symptoms, and stress symptoms. It is also associated with increasing positive attitudes towards work and coping with severe challenges such as poverty. Although few studies have quantified the direct relationship between greenness and mental health, the relationship appears to be strongly supported. One study also found that environments that provide opportunity for social community building and physical activity, both of which can be provided by green infrastructure, are conducive to positive mental health effects. Although the BMPs individually do not necessarily enhance access to parks or recreational opportunities, they could if designed to increase visibility of the green space to the public or increase access. Including recreational opportunities along with the BMPs may augment mental health benefits.

Table 3.6 Summary of Mental Health Benefits by BMP

G2G BMP	Applicable	Relationship	Comment
Ecoroofs	Yes	Associated with improved mental health	Increased vegetation alone may enhance mental health. Benefits would increase with increased visibility and/or accessibility.
Green streets	Yes	Associated with improved mental health	Increased vegetation alone may enhance mental health. Mental health may also be enhanced if green streets increase recreational walking and social cohesion.
Trees	Yes	Associated with improved mental health	Increased vegetation alone may enhance mental health. Mental health may also be enhanced if street trees increase recreational walking and social cohesion.
Invasives removal / revegetation	Uncertain	Possible Positive Effect	Could be applicable if invasive removal increases perceived attractiveness of neighborhood/green space and opportunities exist to view or walk in or to the area.
Culvert removal	No	NA	Culvert removal itself does not increase vegetation and is not expected to affect mental health.
Land purchase	Uncertain	Possible Positive Effect	Could preserve mental health benefits if green space is visible from residences or commercial areas. Mental health benefits would also result if the purchase would result in creation of a new park or usable green space within a neighborhood.
Planting in natural areas	Uncertain	Possible Positive Effect	Could preserve mental health benefits if planting enhances perceived attractiveness of natural areas that are visible from residences or commercial areas. Mental health benefits would also result if the planting increases the attractiveness of recreational activities in a social setting.

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SECTION 4

Energy and Greenhouse Gases

The G2G Initiative is expected to result in a net decrease in energy use and associated carbon dioxide and other greenhouse gas (GHG) emissions. Based on the current research on the G2G BMPs, the energy subgroup identified three primary ways that the BMPs will decrease energy usage. First, many of the BMPs are designed to reduce stormwater generation, which will result in less energy use for stormwater pumping and treatment. Second, nearly all of the BMPs will increase urban vegetation. Increased urban vegetation leads to cooler summertime ambient air temperatures (reduced heat island effect) and thereby decreases energy use for summer cooling. Several BMPs will also increase the insulation and shading of buildings, which is expected to directly reduce building energy use.

Reduced energy use from each of these mechanisms will decrease carbon dioxide and other greenhouse gas emissions as less power generation from fossil fuels is required. Additionally, through planting of trees and other vegetation, several G2G BMPs will increase carbon sequestration in the City. To summarize and describe these energy and greenhouse gas benefits, the subgroup identified the following benefits categories, metrics, and units of measurement.

Table 4.1 Energy and Carbon Benefit Categories, Metrics, and Units

Benefits Categories	Metric	Unit
Energy	Reduced Energy Use	kWh / Year
Greenhouse Gasses	Carbon Sequestration and Emission	Metric Tonne of CO_2 Equivalent / Year

As many of the G2G BMPs are becoming increasingly recognized and utilized in urban environments, their benefits are being increasingly studied but the research is still in its early stages. Therefore, while quantification of some of the energy and GHG effects by BMP is possible (particularly for stormwater pumping), it is important to recognize that there are few existing studies for many of these benefits. Although several of the available studies were conducted in Portland, for some effects there is low certainty associated with benefit estimation, and for other effects estimation specific to each BMP is not possible.

It is important to note that there is increased energy use associated with the materials required to construct some of the BMPs, as well as monitoring and maintenance activities. These energy impacts were considered in this study, but due to lack of data the overall effect is not known or quantitatively estimated. Furthermore, as discussed in Section 1.2, it is anticipated that the results from this study will be eventually used in a cost benefit analysis. It is expected that the energy use for materials and maintenance will be included in the cost analysis for each BMP, and will therefore at least be partially captured in that process. Additionally, this study does not assess the benefits of climate change reduction, such as improved resiliency of habitat and wildlife or potential economic value.

4.1 ENERGY USE EFFECTS

As noted above, the subgroup identified three primary mechanisms, or pathways, through which the BMPs reduce energy consumption: reduced stormwater production, reduced heat island effect, and increased building insulation/shading. For each pathway, the data sources, methodology, and benefit results by BMP are described below.

4.1.1 Stormwater Production Effects

In Portland, stormwater that is generated in the combined sewer area is pumped through the system. Energy use for pumping declines with decreased stormwater production. The BMPs that are expected to result in measurable changes in stormwater production are ecoroofs, green streets, and street trees. It is also possible that other BMPs may reduce stormwater volumes in the combined sewer area, but the project team viewed these savings as speculative and/or minimal.

4.1.1.1 Data Sources and Methodology

Data to calculate energy savings from the BMPs was gathered from BES internal data as well as published literature. Three principal pieces of data were necessary for benefit estimation: the volume of rainfall and stormwater generation in Portland, the quantity of stormwater intercepted by each BMP, and the electricity use per gallon of stormwater. Data on rainfall in Portland and electricity use is based on estimates used internally in BES. Data on stormwater interception for each applicable BMP is from the following sources:

- Ecoroofs: BES 2008 Stormwater Management Facility Monitoring Report, Sustainable Stormwater Management Program (BES, 2008a);
- Green Streets: BES 2008 Stormwater Management Facility Monitoring Report, Sustainable Stormwater Management Program (BES, 2008b); and
- Trees: 2007 Portland Canopy Report, as well as internal data collected by the BES.

To estimate reduced volume of stormwater production, total stormwater generated by area of impervious surface was first estimated (based on an average annual rainfall of 37 inches as used by BES), and then multiplied by the percentage captured by the BMP. In addition, as the benefits from trees will vary depending on tree maturity and size, average annual reductions in stormwater from trees throughout the project life were based on estimates from the 2007 Canopy Report. This report estimates stormwater reduction benefits from a diverse range of street tree sizes and therefore is expected to give a good approximation of average annual benefits from street trees planted by G2G.

For each BMP, the estimate of stormwater reduction was multiplied by electricity savings per unit of stormwater. In 2008, BES engineers estimated an average cost of $0.0002 per gallon of stormwater entering the combined sewer area. This figure is based on historic records and isolating electricity costs (based on electric bills) from other system costs. This estimate was completed for internal use and was not published (Pers. Comm. Liptan).

4.1.1.2 Benefit Estimate and Certainty by G2G BMP

This section presents the estimates for stormwater energy savings for ecoroofs, green streets, and street trees. Culvert removal is not designed to change the amount of stormwater runoff generated, and so is not expected to have an associated energy effect. Stormwater reduction benefits, and associated energy savings, were not estimated for the other BMPs.

Invasive removal and revegetation is typically occurring in natural areas that are not currently producing stormwater runoff, so this BMP is not anticipated to measurably change stormwater runoff quantities. While land purchases can potentially prevent additional development from occurring, the regulations on new developments will limit the additional stormwater that would be generated from these sites even if they were developed. Finally, planting in existing natural areas is not expected to result in a measurable reduction in stormwater runoff entering the combined sewer area.

Ecoroofs

Based on 37 inches of annual rainfall, it is estimated that there are an estimated 1,004,700 gallons of rain falling per surface acre. BES ecoroof monitoring data from the 2008 BES Ecoroof report indicates that Portland ecoroofs retain and evaporate approximately 55 percent of annual rainfall. (Although not all ecoroofs are equally effective at reducing stormwater, it is the intention of BES to develop ecoroofs with maximum stormwater benefit.) Multiplying these figures indicates that every acre of ecoroof will reduce stormwater runoff by 552,600 gallons.

Energy savings are expected to result primarily from reduced pumping in the combined sewer system, so it is necessary to estimate the proportion of ecoroofs that are located in the combined sewer area. Although siting of ecoroofs in the G2G Initiative is not known at this time, BES estimates that 80 percent will be located in the combined sewer area. This indicates that every acre of ecoroof will result, on average, in reduction of approximately 442,100 gallons of stormwater annually to the combined sewer system. Using the BES estimate of $0.0002 of electricity cost per gallon on combined sewer stormwater and an energy price of $0.06 per kilowatt hour (kWh) provides an estimated **annual energy savings per ecoroof acre of 1,470 kWh.**[1] The G2G target is to construct 43 acres of ecoroofs, so total annual energy savings once this target is reached is estimated at 63,400 kWh annually.

Green Streets

Based on 37 inches of rainfall annually, approximately 92,300 gallons of water falls annually on the estimated 4,000 square feet of impervious surface drained by each green street facility. Per past practice in Portland, the size of the green street facility was assumed to be approximately six percent of the contributing impervious drainage area. An assumption that approximately 90 percent of rainfall on impervious areas will become runoff that will enter each green street facility (the remaining 10 percent is incidental infiltration) was then used, resulting in 83,000 gallons of stormwater runoff. (A drainage coefficient of 0.9 is commonly used for impervious surface in the Rational Method, an engineering formula used to determine stormwater runoff rates.) BES monitoring of existing facilities indicates that green streets reduce 90 percent of stormwater runoff, so each green street facility is estimated to decrease stormwater runoff by 74,700 gallons. As with ecoroofs, using the BES estimate of $0.0002 of electricity cost per gallon of combined sewer stormwater, the BES estimate that 62 percent of green streets will be located in the combined sewer area, and an energy price of $0.06 per kilowatt hour (kWh), provides an estimated average **annual energy savings per green street facility of 155 kWh.** The G2G target is to construct 920 green street facilities, so total annual energy savings once this target is reached is estimated at 142,100 kWh annually.

Trees

The STRATUM model used for the 2007 Portland Canopy Report estimated that the 236,521 street trees in Portland captured 135,209,280 gallons of stormwater. The street trees in the Canopy Report represent the full spectrum of species and size of existing street trees, with trees evenly divided between small, medium, and large sized trees. This data indicates that, an average, each existing street tree intercepts 572 gallons of stormwater per year. Assuming that 75 percent of the trees are planted in the combined sewer area, the

[1] Note that the BES reported a cost per gallon of stormwater, rather than electricity use per gallon,. To calculate energy use, it was necessary to convert the cost per gallon to electricity use based on an aveage energy price.

estimated annual energy savings per tree is 1.4 kWh. Average energy savings for the 50,000 street trees is estimated 71,500 kWh annually.

Rainfall interception tests conducted by BES indicate that this figure may be conservative. One test was on a small deciduous tree in early fall, and the study was published in the proceedings of an ASLA Stormwater Conference in 1996. Another test was conducted on a large deciduous tree at the wastewater treatment plant in the late summer, and was documented in BES monitoring records. Finally, a larger study was conducted by BES to measure runoff from residential streets with trees and without trees, with the results also documented in BES monitoring records. These three different studies indicated that the trees intercepted 20 to 38 percent of the rain during the times tested. Based on this information, it is estimated at one mature Portland street tree would intercept and evaporate rain, and transfer stem flow to soil for a total of 13 percent of the annual rain. An average tree canopy size of 36 square meters from the 2007 Tree Canopy Report (see Section 3.1.1 for derivation), indicates that total rainfall on each tree would be approximately equal to 8,938 gallons annually. Assuming a 13 percent capture rate, this would be equivalent to a reduction in stormwater runoff of 1,162 gallons.

4.1.2 Urban Heat Island Effects

The temperatures in urban areas are often significantly higher than in surroundings rural areas. This phenomenon is referred to as the urban heat island (UHI), and results from the generation and retention of heat by urban buildings and paved surfaces. The UHI results in higher energy demand during the summer season, so its reduction is associated with lower summertime energy use. The urban heat island effect can be diminished (i.e. ambient temperatures reduced), by increasing the average albedo (solar reflectivity) and vegetation density of the urban environment. Proper positioning of materials and plant species for BMPs such as ecoroofs, green streets, natural planting, and trees can increase albedo and vegetation density, which in turn will reduce temperatures within and downwind of the UHI.

Through increasing or preserving vegetation density, all G2G BMPs with the exception of culvert removal may dampen the UHI in Portland. Although more data is required to estimate effects specific to the G2G Initiative, this analysis indicates the temperature effects that could be anticipated with different increased levels of albedo and vegetation density.

4.1.2.1 Data Sources and Methodology

The Mitigation Impact Screening Tool (MIST), developed by Dr. David Sailor at Portland State University, was used to evaluate variations in albedo, vegetation density, and resultant temperature effect on the UHI (Sailor, 2005). MIST applies albedo and vegetation increase evenly across an urban study area. Albedo and vegetation values can be defined independently. However, MIST does not differentiate between surface types, such as paved streets and ecoroofs, so when the analyst provides increased albedo or vegetation values, the estimated temperature change from MIST is a cumulative value and does not provide estimates for the effect of specific BMPs. If the percent increase in urban albedo or vegetation is known for a specific BMP, the MIST tool can provide a benchmark temperature reduction for this BMP.

Detailed data related to energy impact of inlet temperature on air cooled packaged air-conditioning systems[2] will soon be available from Mark Modera, University of California at Davis. His work indicates that 80 percent of commercial cooling is by air cooled "packaged" cooling systems. His forthcoming paper will provide quantitative, measured data (not modeled) and analysis on the efficiency effect of changes in inlet temperature (due to mitigation of the UHI) on packaged cooling systems.

[2] Air cooled packaged air conditioning systems are self contained ("packaged") air conditioners that use air as a condensing medium, resulting in more energy use if the air is warmer.

4.1.2.2 Estimation of Benefits

MIST was used to estimate the temperature effects in Portland of increases in albedo and vegetation density resulting from such actions as the G2G implementation of ecoroofs, green streets, natural plantings, and trees. Table 4.2 presents temperature results from the MIST analysis for a range of albedo and vegetation density increases. For example, as illustrated in the Table, a 10 percent increase in albedo and vegetation (over current levels in Portland) is estimated by MIST to reduce urban temperature by 1.6 degrees Fahrenheit or 0.9 degrees Celsius. This temperature reduction of 1.6 degrees Fahrenheit is expected to approximately correspond to a two percent decrease in cooling energy demand for the Portland metro area, (Akbari, 2001; Sailor, 1995) (Akbari, 2001).

Table 4.2 Estimated Portland Temperature Change Due to Increased Albedo and Vegetation Density (Degrees Fahrenheit)

	Albedo (Percent Increase)			
Vegetation (Percent Density Increase)	*0%*	*10%*	*25%*	*50%*
0%	0.00	-0.90	-2.65	-6.65
10%	-0.65	-1.60	-3.30	-7.35
25%	-1.65	-2.80	-4.55	-8.55
50%	-4.65	-2.65	-7.30	-11.35

Values are based on results from Mitigation Impact Screening Tool (MIST), 57.7 degrees Fahrenheit average baseline temperature.

4.1.3 Building Insulation / Shade Effects

Two BMPs directly reduce building energy use by increasing insulation (ecoroofs) or shading buildings (yard and street trees). These effects are in addition to the UHI effect, which cools the ambient air surrounding buildings. The insulation effect of ecoroofs is based on increased thermal resistancy, known as the R-value. More effective insulation increases the R-value and the energy efficiency of a building and decreases the energy transfer between the building and the outside environment (i.e. less heat escaping in winter, less heat entering in summer). Through shading, trees intercept solar energy that would otherwise heat the shaded building. Energy savings from ecoroofs and green streets are the two BMPs that are most likely to provide benefits from building insulation or shade. While other BMPs such as revegetation and planting in natural areas include planting trees that will provide shading, it is not expected that they will be located close enough to buildings to provide direct shade benefits. Additionally, while green streets will often be located close to buildings, it is expected that plants typical for green street facilities will not be tall enough to provide significant shading benefits.

4.1.3.1 Estimation of Benefits

In contrast to other sections, the data sources and the methodology description are integrated with the benefit estimate for the BMPs as the approach to estimating energy savings from ecoroof insulation and tree shading differ significantly.

Ecoroofs

As noted above, the insulation benefit of ecoroofs is based on the degree to which the ecoroof increases thermal resistance, or the R-value. The higher the R-value, the less heat transfer occurs and the less energy is required for building heating or cooling. Different insulating materials have different R-values; by determining the R-value of an ecoroof, the increased R-value and reduced energy requirements of the building can be estimated. The R-values for ecoroofs were obtained from research performed in the Green Roof Test and Design Lab at Portland State University in 2008 (and documented in Harriet Bell's Master thesis). This research indicates that an ecoroof with a five to fourteen centimeter thickness that is planted with sedum, vinca, or rye grass has a mean R-value of 2.73 ft² ºF hr/Btu, while an ecoroof of similar depth that has only bare soil has an R-value of 1.75 ft² ºF hr/Btu.

The mean R-value for bare soil was used to estimate energy savings in winter heating months, as the soil and not the plants provides the majority of the insulation effect in winter months. The R-values of bare soil used here were obtained from a testing unit designed to test ecoroofs during hot climate conditions only, and must be viewed as rough estimations of the real R-value of a ecoroofs during cool times of the year. To estimate the energy effect of the additional ecoroof insulation, it is necessary to estimate the daily building heating requirements. It is assumed that most buildings are maintained at a year-round temperature of approximately 65 degrees, and the difference between the mean daily winter temperature and the desired temperature of 65 degrees is known as a Heating Degree Day (HDD) unit (e.g. if a winter day has a mean temperature of 45 degrees, then the HDD unit for that day is 20; if wintertime temperature exceeds 65 degrees then it is assumed that there is no heating or cooling energy used).

To estimate energy savings in the winter months, this HDD value is multiplied by 24 hours in a day, and then multiplied by the ecoroof-induced change in the heat transfer coefficient (known as the U-value, which is defined as the inverse of the R-value). This returns a daily value in British thermal units (BTUs), which can be converted to annual kilowatt hours. The increase in building energy efficiency due to an ecoroof depends on the starting R-value of the building; the less energy efficient a building is before using an ecoroof, the greater the building energy savings from the ecoroof.

In the summer months when air conditioners are used, the evapotranspiration of the ecoroof plant significantly increases the R-value of the ecoroof. To estimate the energy savings of ecoroofs in the summer cooling months, the mean R-value for planted ecoroofs of 2.73 ft² ºF hr/Btu was used. Similar to the wintertime calculation, the difference between the mean daily temperature and 65 degrees is estimated, but is known as the Cooling Degree Day (CDD) since it is the degrees cooled by air conditioning (rather than degrees heated). The rest of the calculation to estimate annual kilowatt hour savings is the same as for wintertime heating.

Based on this methodology, the annual heating and cooling savings from each square foot of ecoroof for buildings with different starting insulation R-values is presented in Table 4.3. As indicated in the Table, the lower the R-value (indicating a less energy efficient building), the greater the annual energy savings from an ecoroof. Based on average building R-values, it is assumed that buildings that will have a G2G ecoroof start with an R-value of 19, the annual heating savings per square foot of ecoroof is estimated at 0.137kWh and the annual cooling savings is 0.0181 kWh. Assuming that all buildings with ecoroofs are heated and cooled throughout the year, the total annual energy savings of an ecoroof per square foot is 0.156 kWh, and the **annual energy savings from insulation per acre of ecoroof is estimated at 6,800 kWh.** (The equivalent **energy savings** per 1,000 square feet is estimated at 156 kWh per year)**.** The energy savings from implementing the G2G target of 43 acres is estimated to total approximately 292,200 kWh.

Table 4.3 Ecoroof Annual Energy Savings (Average kWh savings/square foot)

Existing roof R-value in ft² ºF hr/Btu	*Heating Savings in kWh/ft² yr	Cooling Savings in kWh/ft² yr	Total Savings a year in kWh/ft² yr
17	0.170	0.0223	0.192
19	0.137	0.0181	0.156
21	0.113	0.0150	0.128
23	0.095	0.0127	0.108
25	0.081	0.0108	0.092
27	0.070	0.0093	0.079
29	0.061	0.0081	0.069
31	0.053	0.0072	0.061
33	0.047	0.0064	0.054
35	0.042	0.0057	0.048
37	0.038	0.0051	0.043
39	0.034	0.0046	0.039
41	0.031	0.0042	0.035
43	0.028	0.0038	0.032

Trees

Trees planted near homes and other buildings provide shading that reduces indoor temperatures and associated demand for air conditioning. A growing body of literature has examined this benefit and estimated the resulting reduction in energy use for building cooling. A recent Donovan and Butry (Donovan, 2009b) study of shade trees around homes in Sacramento estimates a 5.2 percent decrease in summertime electricity usage from trees on the south and east side of homes. Trees planted on the north sides of homes are found to actually increase summertime electricity usage by 1.5 percent. Their results are consistent with, but tending toward the low range of estimates from other literature (Akbari, 1997). As indicated in other literature, the Donovan and Butry study found that the effect of trees on wintertime cooling may be either positive or negative, depending on placement of the tree around the home and the wind, sunlight, and temperature characteristics of the site. As the direction of the relationship between wintertime energy use and yard trees is not clear, this analysis focuses solely on summertime energy use.

The Donovan and Butry study formed the basis to estimate the impacts of trees on summertime energy usage in Portland. Since tree placement of street and yard trees in the G2G Initiative is not known, effects from both types of tree placement (north versus south and east) in the Donovan and Butry study are averaged for an estimated decrease in energy use of 3.7 percent. This analysis also assumes that there are only two months in the year when air conditioning is used. This data is combined with data from Portland General Electric (PGE, 2007) on the number of households with air conditioning in the City of Portland (60 percent), and the average monthly energy use per Portland household (913 kWh). It is assumed that the energy use reduction estimated in the Donovan and Butry study requires four trees per household, so that the effect per tree is approximately a 1 percent decrease in household energy use during the two months that Portland residents use air conditioning (9.13 kWh per month, or a total of 18.26 kWh per tree annually). Assuming yard trees are equally likely to be planted by households with air conditioning as not, 19,800 trees (60 percent of the 33,000 trees) will reduce summertime cooling costs. Multiplying these 19,800 trees by the estimated reduction in electricity usage per tree of 18.26 kWh results in an estimated reduction of 361,450 kWh annually, or an **average of 11 kWh per G2G yard tree annually.**

It is less certain whether street trees will provide this same effect as it depends on the setback distance between buildings and the street planting. If located close enough to buildings to provide shading, it is estimated that they would have the same average effect of **11 kWh reduced annual energy use per G2G street tree.**

4.1.4 Summary of Energy Savings Benefits

Table 4.4 below summarizes the energy savings from stormwater reduction, UHI mitigation, and direct building insulation or shade provided by the BMPs. The estimates of energy savings from stormwater have the greatest certainty as this is the area with the most available research. More information is needed about the location of land purchases and plantings in natural areas to determine if these BMPs would result in less stormwater flowing into the combined sewer area. Although it is known with high certainty that increased vegetation density and albedo in the City will lead to decreased urban temperatures, to quantify the magnitude of this effect requires estimates of the proportional increase by BMP that are currently not available. Finally, the effects associated with insulation and shade are quite uncertain as the location of each BMP largely determines the benefits. For ecoroofs, it is necessary to know how energy efficient a building would be without the ecoroof as well as whether the building would be heated and cooled throughout the year. For trees, to estimate shade effects on building energy use, it is necessary to know where the tree will be located in relation to the building.

Table 4.4 Annual Energy Savings by BMP

BMP	Applicable	Relationship			Total
		Stormwater	Urban Heat Island (UHI)	Insulation/Shade	
Ecoroofs	Yes	1,470 kWh/Acre	Positive Mitigation	6,800 kWh/ /Acre	8,270+ kWh/ /Acre
Green streets	Yes	155 kWh/facility	Positive Mitigation	Possible Positive Effect	155+ kWh/Facility
Trees: yard	Yes	N/A	Positive Mitigation	11 KWh/Tree	11+ kWh/Tree
Trees: street	Yes	1.4 kWh/Tree	Positive Mitigation	Possible 11 KWh/Tree if located close to buildings and large enough to provide shade effect	Potential 1.4+ kWh/Tree
Invasive removal / revegetation	Uncertain	Possible Positive Effect	Possible Positive Mitigation	Possible Positive Effect	Possible Positive
Culvert removal	No	N/A	N/A	N/A	N/A
Land purchase	Uncertain	Possible Positive Effect	Preservation of Mitigation	Possible Positive Effect	Possible Positive
Planting natural areas	Uncertain	Possible Positive Effect	Positive Mitigation	Possible Positive Effect	Positive

4.2 GREENHOUSE GAS EMISSIONS

This section discusses the greenhouse gas (GHG) impacts of the G2G BMPs. Effects on carbon dioxide (CO_2) and other GHGs are important to consider because of their contribution to climate change, which is increasingly understood to have significant potential to disrupt ecological and economic systems. Reducing GHG emissions is the goal of Portland's Climate Action. The BMPs affect both the production of GHG, and the removal of GHG from the atmosphere, primarily through sequestration of CO_2.

Both of these effects on GHGs are considered: reduced GHG emissions from reduced energy consumption, and increased sequestration of carbon dioxide by vegetation. Reduced GHG emissions are first estimated based on the reduced energy use estimated above for lower stormwater pumping and building heating and cooling requirements (via both UHI mitigation and direct building shading/insulation).[3] Increased sequestration of carbon by vegetation planted under the G2G Initiative is then estimated.

4.2.1 Reduced Greenhouse Gas Emissions

Since much of the electricity consumed in Portland is produced from fossil fuels, reducing electricity energy use indirectly reduces the burning of fossil fuels and the release of GHGs. To estimate the change in GHG production that results from reduced energy use, it is necessary to determine the quantity of GHG that is produced for each unit of electricity consumed. This amount depends on the mix of power sources and the efficiency of the generation plants.

4.2.1.1 Data Sources and Methodology

There are numerous types of GHG, each with a different level of climate change effect. A standard unit has been developed, known as a carbon dioxide equivalent (CO_2e) unit, which is used to express the climate change effect of each GHG. For example, methane is about 22 times more potent as a greenhouse gas than CO_2, so each unit of methane is equivalent to about 22 CO_2e units. In this manner, all GHG can be converted to CO_2e units.

Reduced GHG emissions in this report are expressed in metric tonnes of CO_2e, which is the most commonly reported unit. However, it is important to recognize that CO_2 is sometimes expressed in tons (2,000 lbs) and sometimes in metric tonnes (2,204.6 pounds). Also, instead of presenting weights in terms of CO_2, some studies present weights in terms of carbon. The conversion is based on the atomic weight of the elements carbon (C) and oxygen (O); one metric tonne of carbon is equivalent to 3.67 (44/12) tonnes of CO_2.

Although this analysis focuses on GHG emissions from electricity production, Table 4.5 below presents information on estimated GHG production (expressed in CO_2e) from a wider variety of energy sources used in Portland. The estimates for electricity production are adjusted upwards by 10 percent to account for the transmission/distribution losses between the generation plant and end users.[4] Also, the figures in the table represent the GHG emissions strictly from the burning of the fuel and do not include any emissions prior to the fuel arriving at the point of combustion (i.e., this is not a life cycle assessment and does not include emissions from fuel production and transport).

[3] Although the BMPs may also affect the amount of transportation fuel used, this effect is more difficult to estimate and the net effects of the BMPs is not clear, so it is not considered in this analysis.

[4] This is an approximate adjustment to account for line and transformer losses. One source for the adjustment is http://www.pacificorp.com/File/File74765.pdf

Table 4.5 Energy to Carbon Factors

Energy Source	Energy Units	Pounds CO_2 e per Unit
Portland General Electric electricity	Kilowatt-hour (kWh)	1.375/kWh*a/
Pacific Power electricity	Kilowatt-hour (kWh)	2.08/kWh b/*
Natural gas	Therms	11.7/therm c/
Gasoline	Gallon	19.4/gallon d/**
Diesel	Gallon	22.2/gallon e/**

a/ http://carma.org/company/detail/15833
b/ http://carma.org/company/detail/45520
c/ http://revelle.net/lakeside/lakeside.new/understanding.html
d/ http://www.epa.gov/OMS/climate/420f05001.htm
e/ http://www.epa.gov/OMS/climate/420f05001.htm

Despite several sources of uncertainty regarding these estimates, the overall level of certainty in these estimates is high. The emissions values for the electric utilities are based on the average annual generating hours and fuel sources used for entire utility systems. If the electricity savings resulting from a G2G BMP occur at a certain time or season, then the actual effects may differ because the generating fuel mix may differ during certain seasons. The adjustment for transmission losses is an approximate value, but it is within a percent or two of the actual value for specific conditions and is a relatively small adjustment. Another source of uncertainty is how fuel mixes may change over time; this analysis assumes that the current fuel mix used by the electric utilities remains the same. While both Portland utilities are seeking to increase their share of renewables, there may be increased pressure to use more coal (which with current practices results in relatively high emissions of CO_2) to meet demand.

4.2.1.2 Benefit Estimation and Certainty Level

Based on the annual energy savings estimated above and presented in Table 4.4, the total reduced carbon emissions were calculated. As all energy savings were calculated in terms of electricity use savings, carbon emissions were based on an average of the two Portland electric utilities: Portland General Electric and Pacific Power. The average CO_2 emissions per kilowatt hour of electricity usage are 1.7275 pounds of CO_2 (see Table 4.5). Multiplying this value by the energy savings from Table 4.4 results in the estimates of reduced emission presented in Table 4.6. As indicated in Table 4.6, the energy savings and associated reduced CO_2 emissions are greatest for ecoroofs due to their insulating effect on buildings. Emissions reductions are presented for each BMP unit (i.e. tree, facility, etc) as well as for total reduction once the G2G implementation target is reached.

Table 4.6 Summary of Annual Reduced GHG Emissions (Metric Tons CO2e) by BMP

G2G BMP	Applicable	Emissions Reduction Per BMP Unit	Total Emissions Reduction at G2G Target
Ecoroofs	Yes	6.480 Tons / Acre / Year	278.65 Tons / Year
Green streets	Yes	0.196 Tons / Facility / Year	5.22 Tons / Year
Trees: yard	Yes	0.009 Tons / Tree / Year	0.37 Tons / Year
Trees: street	Yes	0.001 Tons / Tree / Year	0.42 Tons / Year
Invasive removal / revegetation	Uncertain		
Culvert removal	No		
Land purchase	Uncertain		
Planting natural areas	Uncertain		

4.2.2 Carbon Sequestration

Carbon sequestration refers to the removal of CO_2 from the atmosphere or the prevention of CO_2 entering the atmosphere. Our focus is terrestrial sequestration, which removes CO_2 from the atmosphere and stores it for long periods in vegetation or soil. Most commonly it is converted into biomass in the form of trees, shrubs, and other vegetation. In addition to planting vegetation, carbon sequestration can occur through land management practices. According to the West Coast Regional Carbon Sequestration Partnership:

> "… land management practices can be altered to decrease the decomposition of organic matter (which releases CO_2) and to sustainably increase the rate of plant photosynthesis;…harvested trees can be used to produce long-lasting products, such as high-quality building materials and furniture, that can keep captured CO_2 from re-entering the atmosphere;…. forests that are choked with brush, invasive plants, or an unhealthy number of small trees can be managed to reduce 'fire fuels' by removing this material for renewable biomass power production. This approach helps control the severity of fires and the associated ecological damage and massive CO_2 emissions" (West Coast, 2009).

For the G2G BMPs, the source of carbon sequestration is increased vegetation biomass, either through planting of vegetation or through preserving vegetation in areas where the vegetation might be removed through development. This section estimates the amount of carbon sequestered by each BMP.

4.2.2.1 Data Sources and Methodology

Protocols have been developed for calculating carbon emissions and sequestration. This section describes several protocols pertinent to this analysis, as well as the types of data and general methodology followed to estimate carbon sequestration by each BMP.

The most widely accepted protocol is the World Resources Institute GHG Protocol (GHGPI, 2009). Although this protocol establishes clear procedures to guide analysis and reporting, the GHG Protocol lacks guidelines to assess the sequestration impacts of the G2G BMPs. While there is no "adopted" protocol for analyzing such BMPs, there are several protocols, calculation methodologies, and tools available that were examined for use in this study.

The California Climate Action Registry (CCAR) Urban Forest Project Reporting Protocol (CUFR) provides standards and guidance for reporting GHG emissions and reductions for all trees owned, controlled, or managed by the reporting entity. This protocol focuses on carbon storage in trees and how the urban forest's carbon stocks will change over time. Indirect GHG emission reductions associated with energy savings from tree shade or bioenergy are reported by the entity in the General Reporting Protocol. This protocol is relevant to organizations desiring to quantify entity-wide carbon stocks, and to entities engaging in urban forestry activities (Climate Action Reserve, 2009). Key specifications of the protocol include:

- Projects that ensure carbon storage through tree planting and maintenance to increase and prolong carbon storage in urban forest carbon pools are eligible.
- The reporting organization must own, manage, or control project trees.
- The organization must give an indication of how long the project will be valid, typically 30-50 years; the California protocol requires 100 years.
- To maximize future benefits and minimize the risk of loss, urban forestry projects must report the type of mechanisms instituted to promote long-term carbon security.
- It must be demonstrated that the project meets additionality requirements, i.e., it will result in carbon storage that is additional to the baseline that would occur without the project, and it exceeds any regulatory requirements. Sequestration is counted for only those trees considered additional, representing net tree gain (NTG).

- Incremental emissions from vehicles and equipment to maintain the trees counted for sequestration must be taken into account.
- Annual monitoring is required to verify carbon sequestration matches estimates from growth models and project complies with the protocol.

To estimate the amount of carbon sequestered by plants from the atmosphere into the plant matter and the soil requires assumptions regarding soil type, below ground biomass, soil organic matter saturation, and the size, species, and age of vegetation. Given these many variables, the actual amount of carbon sequestration can vary widely.

The age of vegetation affects the amount of carbon uptake in the above ground and below ground plant matter, which then affects the carbon uptake in the soil. This study indicates that over time a great deal of sequestration in biomass can occur below the soil and should be taken into account. A study was performed looking at the *Abies amabilis* forests in the Washington Cascades Mountain range to look at this difference (Schlesinger, 1997). For comparison, the amount of net primary production was examined for trees ranging from 23 to 180 years old in grams per meter squared per year. It was found that the 23 year old trees had about 27 percent of the biomass above ground and 73 percent below ground, whereas the 180 year old trees had only 18 percent of net primary production above ground.

The soil also contains carbon in the form of organic matter, so when estimating sequestration it is important to determine the actual amount of organic matter and soil type. One article states that a cubic foot of silt-loam soil weighs roughly 85 pounds, and that the top 8 inches of soil is a good depth for estimation of the amount sequestered. Organic matter is about 58 percent carbon; thus, for every one percent organic matter in soil, there are about 0.3 pounds of carbon per square foot. Soil in a garden can have 7.7 percent organic matter content and therefore contain 2.5 pounds of carbon per square foot (Meadows, 2000). Consequently, it is important to determine the actual amount of organic matter and soil type when calculating sequestration for a specific area. According to soil survey data, typical soil in Oregon contains about 2 percent carbon.[5]

Finally the type of vegetation on the soil can have a large effect on the amount of carbon sequestered. The table below presents the widely varying levels of carbon density within different types of vegetative cover (Schlesinger, 1997). This data was utilized to estimate the carbon sequestration that may result from the G2G green street BMP.

Table 4.7 Carbon Sequestration by Vegetation Type

Vegetation Type	Mean Plant Biomass (grams of Carbon / ft^2)
Temperate Forest	743.5
Temperate Steppe	278.8
Wetland	250.9
Cultivated Land	130.1

While carbon sequestration by green streets were based on estimating each of the above factors, tree and ecoroof sequestration estimated were based on published data on sequestration by these BMPs. Ecoroof sequestration is based on a recent paper presented at the Greening Rooftops for Sustainable Communities in June 2009 entitled "Carbon Sequestration Potential of Extensive Green Roofs" analyzing ecoroofs in Lansing, Michigan. Tree sequestration is based on sequestration by urban trees in Portland is based on results from the 2007 Canopy Report, which uses the STRATUM model. This report provides total sequestration values on an annual basis as well as total cumulative stored carbon for all public trees in Portland. However, it is

5 Estimated from the range of data provided in: Homann, P. S.; Sollins, P.; Fiorella, M. ; Thorson, T. ; Kern, J. S. 1998. "Regional Soil organic carbon storage estimates for western Oregon by multiple approaches," Soil Science Society of America journal vol. 62, n°3, pp. 789-796

important to note that the CUFR Tree Carbon Calculator (USFS, 2009) is the only tool approved by the CCAR for quantifying carbon dioxide sequestration from GHG tree planting projects. The CTCC is programmed in an Excel spreadsheet and provides carbon-related information for a single tree located in one of six California climate zones.

4.2.2.2 Benefit Estimation and Certainty Level

The following sections briefly describe each of the BMPs and information available to assess their carbon sequestration effects. Each section explores current quantitative and qualitative approaches for assessing sequestration and, where possible, presents best available estimates of the sequestration expected from each BMP. Table 4.8 below summarizes the carbon sequestration benefits estimated for each of the BMPs estimated to increase carbon sequestration in vegetation or soil.

Benefits are estimated for each of the BMPs that would lead to additional vegetation or biomass: ecoroofs, green streets, trees, and planting in natural areas. Purchase of lands in natural areas results in a carbon sequestration benefit if these lands would otherwise be developed, which is uncertain. No benefits are estimated for culverts, although sequestration may increase in downstream areas that are restored to wetland conditions. Finally, long-term sequestration benefits are possible from removing invasive and planting natural species, but as the short-term effects may be negative due to removal of invasive vegetation, the net effect on sequestration is uncertain.

Table 4.8 Summary of Annual Carbon Sequestration by BMP

G2G BMP	Applicable	Relationship (Metric Tonnes CO_2 Removed from Atmosphere/Year))	Comment
Ecoroofs	Yes	0.58 tonnes CO_2/Acre	Sequestration benefits are highly uncertain as they are based on data from a different location.
Green streets	Yes	0.068 tonnes CO_2/Facility	Sequestration benefits have medium certainty as they are based on numerous assumptions, require high organic soil content, and good maintenance of the green street facility.
Trees	Yes	0.076 tonnes CO_2/Tree	Sequestration benefits have a high degree of certainty if trees are rapidly replaced when necessary.
Invasive removal / revegetation	Uncertain		Net effect on biomass in short-term is unknown, likely long-term net sequestration benefits.
Culvert removal	No		Some energy use in project construction, but likely offset by additional sequestration due to habitat restoration.
Land purchase	Uncertain		If land would otherwise be developed, stored carbon in trees and soils would be preserved.
Planting natural areas	Yes	7 tonnes CO_2/acre	Carbon will be sequestered in the trees planted in this BMP, additional sequestration may result from other vegetation that is planted.

4.2.2.3 Ecoroofs

Clearly ecoroofs provide carbon sequestration benefits; however, there is a lack of readily available data measuring the level of sequestration provided. A recent paper presented at the Greening Rooftops for Sustainable Communities in June 2009 entitled "Carbon Sequestration Potential of Extensive Green Roofs," provides carbon quantities for initial sequestration in a set of twenty ecoroof plots in Lansing, Michigan. Averaged over all the plots, the sequestration benefits of the substrate, underground biomass, and above-ground plant material provided a total of 1,187 grams of carbon per square meter (g C/m^2). The values ranged from 144 to 465 g C/m^2 for four different varieties of sedum, with *sedum kamtschaticum* having the highest value and *sedum acre* having the lowest. The actual value for a specific ecoroof will depend on geographic area and many variables such as substrate depth, irrigation techniques, plant variety and quantity, climate, and other factors. Ecoroofs with grasses or leafy plants could have considerably higher sequestration values.

Using the mean sequestration value from this study, typical sequestration would be 10,600 pounds of carbon per acre, or 4.81 metric tonnes of carbon (cumulative value across time). This is equivalent to 17.64 metric tonnes of CO_2 per acre. Averaging this value across thirty years, the **sequestration value of ecoroofs is approximately 0.58 metric tonnes per acre per year**. Implementation of the 43 acres of ecoroofs would result in an estimated 25.3 metric tonnes of carbon sequestered annually.

In addition to the substrate and plants, the structural and drainage materials for the roof and substrate should be considered. The paper cited above indicates that the carbon emissions associated with expanded slate in the substrate is more than 15 times the carbon sequestered by the ecoroof. Consequently, using this type of substrate material could easily overwhelm the sequestration benefits of the ecoroof so one design consideration would be to avoid using expanded slate.

To date, very little research has been conducted on the sequestration impacts of ecoroofs. Additional research on other plants, conditions in the Pacific Northwest, and different substrate materials is essential to quantify ecoroof sequestration more accurately.

4.2.2.4 Green Streets

The introduction of bioswales and increasing vegetative cover on urban streets boosts carbon sequestration and provides stormwater recharge and filtration functions. A GHG protocol that specifically addresses green streets was not identified, so accounting for sequestration would likely require developing a methodology based on general protocols and providing sufficient evidence that it met the fundamental requirements of the general protocol. Sequestration provided by G2G green streets is difficult to estimate as the vegetation and soil type is not known with certainty. The analysis below is based on best estimates of these variables to provide an approximate carbon sequestration value for G2G green streets.

The ground biomass is assumed to equal 25 percent of the above ground biomass, and above ground biomass can be approximated by a temperate steppe vegetation type (consisting of mainly grasses and shrubs). This indicates that there are approximately 279 g of carbon per square foot of vegetative cover, and 70 grams of carbon per square foot below ground. Furthermore, it is estimated that organic matter comprises 10 to 15 percent of soil volume[6] in the soil. Assuming that one cubic foot of silt-loam soil weighs roughly 85 pounds, and that the top 8 inches of soil is a good depth for estimating the amount sequestered, there are approximately 4.11 pounds of carbon per square foot of soil. In total, then, there are an estimated 4.89 lbs of carbon, or 17.93 pounds of CO_2, sequestered per square foot of green street on a cumulative basis (e.g. total sequestration across years can reach this value). The maintenance procedure for Green Streets includes periodic trimming of vegetation, and large-scale removal of plants and soils every 10 years or so to rehabilitate the facility. Removed plants and soils will likely slowly release their stored carbon over time. However, as these plants and soils will be replaced, it is expected that once the green street facility is established the total sequestration (accumulated in the green street facility as well as temporarily stored in the removed plants and soils) at any given point in time will be approximately 18 pounds of CO_2 per square foot of soil.

As green street facilities average size is 250 square feet, there are approximately 2 tons of CO_2 sequestered per green street facility. Averaged across 30 years, the **average annual sequestration is approximately 0.068 metric tonnes per year per green street facility.** In this estimate, the carbon content of the soil is the

6 Soil specification in City Standard Construction Specifications, 2007.

major factor. Consequently, the sequestration estimate is most affected by variations in the soil carbon content. To ensure this level of sequestration, it is important for green street designs to follow the specifications and have soils with consistently high organic content.

4.2.2.5 Trees

Planting trees, such as Oregon's native Big Leaf maple or Douglas fir, offers a range of benefits including carbon dioxide sequestration, also referred to as cumulative storage. The main factor impacting the amount of carbon dioxide sequestered is tree age, although other elements such as the tree's height, width, and canopy impact its ability to sequester carbon dioxide.

To estimate sequestration by trees planted in the G2G Initiative, data were drawn from the 2007 Portland Canopy Report. This data source was used (over the other available tree sequestration calculators such as the CUFR), since it contains data specific to the mix of trees currently planted in Portland. These data are consistent with the calculations used for the energy and stormwater benefits of trees that are also in this report. The Canopy Report states that 10,834,169 pounds of carbon, or approximately18,000 metric tonnes of CO_2, are sequestered annually by the 236,521 street trees in Portland. This is equivalent to **0.076 metric tonnes CO_2 per tree.** Based on this calculation, the 33,000 yard trees to be planted in the G2G Initiative will likely sequester 2,512 metric tonnes CO_2 per year and the 50,000 street trees 3,807 metric tonnes CO_2 per year.

As the City intends to ensure the survival or replacement of the G2G trees, no fatality rate is built into this calculation. The biggest sources of uncertainty in carbon sequestration by trees are tree species, health, and replacement rate of trees. If the current mix of trees is used for future plantings, and if trees are replaced as they die, then the estimated values should be quite accurate. The benefits of carbon sequestration depend on the survival rate and maintenance of tree health. Therefore, an adequate maintenance budget should be considered when planning for long-term carbon sequestration by trees.

4.2.2.6 Invasive Removal/Revegetation

Removing invasive species, such as English ivy and Japanese knotweed, and replacing with indigenous shrubs or trees will eventually lead to a net gain in biomass overtime since if uncontrolled invasive species can lead to tree death and limit biodiversity and biomass in a forest. However, in the short-run, invasive removal may actually result in decreased biomass and decreased sequestration. Due to the varying short-term and long-term effects of this activity, and the variation in invasive removal and revegetation activities, impacts of this BMP on carbon sequestration were not estimated.

4.2.2.7 Land Purchases

Land purchased for conservation and re-vegetation may provide a carbon benefit; if the lands would otherwise be developed then the land purchase will result in the preservation of the carbon sequestered in the vegetation. However, the degree of preservation benefit depends not just on whether development would have occurred, but also the use of any biomass that may be removed if there is development. For example, if the vegetation is burned, this will immediately release CO2 into the atmosphere, but if any wood products are used to make lasting products, such as furniture, then the CO2 could remain sequestered for years to come. Due to the significant uncertainty regarding what would occur on these lands in the absence of land purchase by BES, carbon sequestration benefits are not estimated.

4.2.2.8 Planting in Natural Areas

Planting in natural areas is estimated to include the establishment of 32,000 additional trees. Using the data from above, the average carbon sequestration is estimated at 0.076 metric tons CO_2 per tree annually. This indicates that the 32,000 trees will sequester approximately 2,436 metric tons of CO_2 annually. Assuming even distribution of trees across the 350 acres to be planted, **each acre will sequester an additional 7 metric tonnes per acre**. Additional soil and vegetation sequestration may result from planting in natural areas, but this value is not estimated as the existing soil carbon content is not known, nor is it known whether existing vegetation will be replaced.

SECTION 5

Community Livability

G2G BMPs increase, restore, and improve vegetation in both developed and natural areas throughout the City. Numerous studies link vegetation and green spaces in urban areas to a wide variety of community benefits including increased access to nature, social connections, recreational opportunities, walkability, and reduced crime rates. These community and aesthetic benefits can be difficult to quantify, and the causal relationships between vegetation/greenness levels and community livability is not always clear. Increasingly, however, research confirms that trees, vegetation, and green spaces have positive effects on the community.

To the extent possible, the community livability subgroup sought to identify categories that encompass the broad range of G2G-related community benefits while minimizing the degree of overlap. The final selections were influenced by the availability of data, the applicability of available research to the Portland urban area, and the relevance of the metrics to the Grey to Green BMPs. Benefit categories are amenity value/aesthetics, community cohesion, environmental equity, and access to nature (improvement in overall access or exposure to nature in the urban environment). Selected metrics for each benefit category are presented in Table 5.1

Table 5.1 Community Livability Benefits Categories, Metrics, and Units

Benefits Categories	Metrics	Units
Amenity/Aesthetics	Property Values	$
Community Cohesion	Social Capital Crime	Qualitative
Environmental Equity	Location of Projects	Proportion in Low Income / Minority Areas
Access to Nature	Number of People Affected by Projects	Number of People Passing Annually

A brief description of these metrics and why they were selected is provided below. More detailed information is provided in Sections 5.1 through 5.4.

- Property values rise in areas with enhanced aesthetics and amenities and can thus be used as a measure of the neighborhood benefits associated with trees, open and natural spaces, and green infrastructure.
- Social capital is the concept that individuals and the community benefit from individuals knowing their neighbors and having supportive social networks. Studies have found that vegetation in urban areas encourages use of outdoor spaces and fosters more social interaction. These interactions and the social capital they generate support community cohesion by increasing a sense of well-being, concern for one's neighbors, and the social health of the community in general.
- Crime rates in areas with more vegetation are often lower, possibly demonstrating the increased community cohesion fostered by green spaces. Vegetation may also discourage crime in other ways, such as having a calming effect, by giving the impression that a property is well-maintained and attended, or by increasing the number of people outdoors (i.e., more "eyes on the street" result in less crime).
- The location of projects in diverse socio-economic areas throughout the City can foster environmental equity by creating a more even distribution of green areas in the City.
- The number of people affected by projects is a different way of capturing the degree of benefit from the G2G BMPs that create greener spaces for people to view or recreate in, create habitat for wildlife that people can view and enjoy, and generally improve access to nature. By estimating the number of people

affected by various G2G projects, we can demonstrate that access to nature has been enhanced for a certain portion of the City's population. This access provides community livability benefits as discussed in this section and also health benefits as discussed in Section 3.

5.1 AMENITY/AESTHETICS

Numerous studies have been conducted that explore how property values increase in locations near green infrastructure and open space. The approach used considers all properties within an area, and employs regression analysis to isolate the degree of price difference that is attributable to individual property characteristics. The technique is called the hedonic property value method. Fortunately, several hedonic property value studies have been conducted in the Portland area and have addressed the question of how trees, open space, and increased vegetation have an impact on property values in the City. As described above, this report uses property values as a metric or proxy for the benefit of improved aesthetics and amenities within the City, and so hedonic property value studies were sought that linked property values explicitly to G2G BMPs or similar environmental features.

5.1.1 Data Sources and Methodology

The hedonic property value method measures incremental differences between homes that possess or are near specific environmental amenities. For some of the G2G BMPs the livability subgroup was unaware of relevant studies completed in Portland. In these cases data may have been applied from a study in another city or location. This approach provides a useful indicator of value but entails more uncertainty than studies completed in the Portland area. Also due to a general lack of property value studies on ecoroofs, there is not enough data to determine the amenity and community value of this BMP (David Evans, 2008). There is also a lack of available data on the effects of invasive removal and the relationship of this BMP to property values is uncertain.

Property values only capture the level of benefit to nearby property owners. They do not incorporate the value of green infrastructure to people who do not live very close to the green space but who may still enjoy benefits (the inclusion of the access to nature metric is aimed at including the benefits to the wider public and not just property owners). Depending on the BMP, the property value related to an amenity may accrue to nearby neighbors, or it may accrue primarily to a single household. For example, the amenity measure of an ecoroof might well accrue to neighbors, and not to the owner of the ecoroof. The value of a yard tree, on the other hand, typically accrues to the owner of the home more than to neighbors. For street trees, studies have examined how trees improve the value of the nearest home as well as the value of the neighborhood.

Another consideration when studying property value is that improved home values do not capture exclusively the amenity value of the G2G BMPs, but could also reflect the value of improved community cohesion, access to nature, or walkability. Listed below are the primary studies utilized in estimating the effect of G2G BMPs on home value:

- Donovan, Geoffrey H. and David T. Butry, Market Based Approaches to Tree Valuation, Arborist News 2008(August): 52-55.
- Lutzenhiser, Margot, and Noelwah Netusil, (2001), The Effect of Open Spaces on a Home's Sale Price, *Contemporary Economic Policy* 19(3):291-298.
- Steiner, Carol F. and John B. Loomis (1996) Estimating the Benefits of Urban Stream Restoration using Hedonic Price Method. Rivers 5(4): 267-278.
- Ward, Bryce;MacMullan, Ed;Reich, Sarah, (2008). The Effect Of Low-Impact-Development On Property Values *Proceedings of the Water Environment Federation*, Sustainability 2008 , pp. 318-323(6)

5.1.2 Benefit Estimation and Certainty Level

As noted above, the availability of data varies for each G2G BMP. There are a few studies that combine the effects on property values of a combination of BMPs. For example, a Seattle study explored the relationship between property values and a green streets BMP, bioswales, and culvert removal combined. The results found a 3.5 to 5 percent increase in property values due to the three BMPs combined (Ward, 2008). Findings most pertinent to trees, purchase of natural areas, and planting in natural areas are summarized in Table 5.2, and then described in more detail below.

Many of the values stated in this section provide evidence that people are willing to pay more (to different degrees) for natural amenities in or near their homes or real property. However, the studies of property value increases were primarily conducted by isolating just one of the BMPs discussed. As such, if more than one BMP is in place, it does not typically mean that the home value incremental increases could be added up for a total estimate of improved property value. Rather, if there were several elements affecting home value on one property, it is more likely that the combined effect would be less than the sum of all incremental effects.

Table 5.2 Summary of Amenity/Aesthetic Value Based on Effect of BMPs on Property Value

G2G BMP	Applicable	Relationship	Comment
Ecoroofs	Uncertain	Unknown, if relationship exists, likely positive.	In a recent study of Portland ecoroof benefits and costs, the authors concluded that not enough information was available to assess this benefit.
Green streets	Yes	3.5 to 5 percent increase in home values was seen with green streets + swales + culvert removal	Study demonstrates a collection of improved values for proximity to green streets, swales, and culvert removal. It is not possible to disaggregate this result, but together it provides an estimate.
Trees	Yes	$7,953 Increase in home value per tree in front of house. Benefits to neighboring home values could add another $7,098 per tree.	Yard trees increase values up to a certain percent of canopy, but then can diminish values. Also, the effects of 50,000 yard trees could alter the relationships included in the study since it measurably increases the total canopy cover throughout the City, thereby potentially altering the value of each additional tree.
Invasives removal / revegetation	Uncertain	Some positive, potentially some negative.	Insufficient information is available about this effect. Several studies have shown that invasive removal is desirable, but it is unclear how this might affect property values, or the amenity value of a home or neighborhood.
Culvert removal	Yes	3.5 to 5 percent increase in home values was seen with green streets + swales + culvert removal	Study demonstrates a collection of improved values for proximity to green streets, swales, and culvert removal. It is not possible to disaggregate this result, but together it provides an estimate.
Land purchase	Yes	3.5 to 5 percent increase in home values was seen with green streets + swales + culvert removal	This estimate of increased home value would be higher for homes closer to the area, and lower for homes farther away. Homes between 1,000 and 1,500 feet from the natural area were also seen to increase in value up to 15 percent increase.

G2G BMP	Applicable	Relationship	Comment
Planting in natural areas	Yes	Positive. One study suggests 3-13 % increases in property values for stream restoration efforts. However this does not necessarily match BMP elements.	Several studies have shown that improving the quality of plantings in natural areas is desirable, and people would be willing to pay increments. However, BMP details do not match any known studies for amenity value.

5.1.2.1 Trees

Tree planting has been studied extensively within Portland using the hedonic property value method. Donovan and Butry (2008) studied how street trees improve property values in Portland neighborhoods, and found that the home in front of a street tree had property values on average $7,953 more than others without trees, and that an additional $7,098 accrued to immediate neighbors. The value of yard and street trees is shown to increase values, but at some point can begin to diminish values. That is, more trees are not always better if the canopy crowds out sunlight, or is otherwise not considered desirable.

5.1.2.2 Purchase of Natural Areas

Lutzenhiser and Netusil studied how home sale prices increased when (all other things equal) the home was near a natural area. A natural area park was defined as a place where more than 50 percent of the park is preserved in native and/or natural vegetation, and park use is balanced between preservation of natural habitat and natural resource-based recreation. Parcels with no public access were also included in this category. Seven categories of home distance from a natural area park were studied; in the middle category (a distance to the park of 600 – 800 feet) home values were found to have increased by $11,269 in 1990 dollars or 17.0 percent of the home value.

Assuming that there are more homes farther away from the park than in the closer zones, and for the purpose of estimating values for the G2G BMPs, the fourth distance category (a distance of 801 to 1,000 feet away from the natural area) is selected as a proxy for the average home value increase. Homes in this category were found to have an increased value of $14,798, or 13.6 percent of home value. [7] If a new natural area were purchased inside the Portland area, it is possible that this purchase would preserve an estimated average of $14,798 in future home sale value for all homes within 1,000 feet of the purchase. In many cases, such incremental home value is currently imbedded in the home prices. However, when G2G secures the conservation of green space with the purchase of natural areas, this value is assumed to be preserved for the future (and not lost as would occur if the parcel would otherwise be developed).

5.1.2.3 Planting in Natural Areas

Planting in natural areas is generally considered to improve the quality of open space and therefore is associated with improved amenity value. No studies were found that measured the effect of this type of improvement on property values; however, several studies have estimated individual homeowner willingness to pay for improved vegetation such as for streambank restoration. One study in California found that residents were willing to pay between 3 and 13 percent of their home value to see a streambank restoration program adopted (Steiner, 1996).

[7] Original study value was of $8,981 in 1990 dollars, this value was adjusted to 2008 dollars using the Consumer Price Index.

5.2 COMMUNITY COHESION

Trees, vegetation, and green spaces enhance community cohesion by promoting the use of outdoor spaces, which in turn fosters social connections among neighbors and more surveillance on the street. These factors help foster a sense of well being, potentially improve neighborhood resiliency in times of need (i.e., neighbors who know each other are more likely to help one another), and reduce neighborhood crime rates. To capture these aspects of community cohesion, two metrics were selected: social capital and crime. In comparison to property values, for which there is a large literature, there are relatively few studies estimating the effects of green infrastructure on community cohesion. Due to the inherently qualitative nature of community cohesion and the paucity of relevant studies, this benefit of G2G BMPs is discussed qualitatively.

5.2.1 Social Capital

Social capital is the benefit that individuals and communities derive from having social contacts and networks throughout their communities and is based on the notion that individuals who interact with each other will support each other to the benefit of the entire community. Social capital can be increased by vegetation in urban areas where people can potentially engage in social activities outdoors, so may be increased by such G2G BMPs as ecoroofs, green streets, purchase of natural areas, and tree plantings. Other BMPs such as planting in natural areas, culvert removal, and removal of vegetation may increase vegetation or improve aesthetics, but are unlikely to generate social capital benefits are unlikely as these BMPs are typically in areas distant from neighborhoods where social interaction would occur.

5.2.1.1 Data Sources and Methodology

The University of Illinois, Urbana-Champaign's Landscape and Human Health Laboratory has conducted numerous studies to assess whether arboriculture (cultivation of trees) contributes to social capital and healthy "social ecosystems." Looking at indicators such as ties among neighbors, sense of safety and adjustment, supervision of children in outdoor spaces, patterns of children's play, use of neighborhood common spaces, number of incivilities, and number of crimes, researcher Frances E. Kuo argues that the presence of well-maintained trees and vegetation contributes to vital, well-used neighborhood common spaces. These spaces "serve to both strengthen ties among residents and deter crime, thereby creating healthier, safer neighborhoods" (Kuo, 2003).

Most of the data available on the relationship between vegetation and social capital originates from the Landscape and Human Health Laboratory at the University of Illinois (Urbana-Champaign). Research has been conducted primarily in Chicago's inner city. While Portland's physical and socio-economic environments differ from that of Chicago's, the information in the following articles provides useful insight into how vegetation and green spaces affect a community:

- Kuo, F. E. The Role of Arboriculture in a Healthy Social Ecology. Journal of Arboriculture, 2003. 29 (3): p. 148 – 155.
- Kuo, F. E., W. C. Sullivan, R. Coley, and L. Brunson. Fertile Ground for Community: Inner-City Neighborhood Common Spaces. American Journal of Community Psychology, 1998. 26 (6): p. 823-151.
- Sullivan, W.C., F.E. Kuo, and S. DePooter. The fruit of urban nature: Vital neighborhood spaces. Environmental Behavior 2004. 36 (5): p. 678-700.

5.2.2 Benefit Estimation and Certainty Level

Several studies have shown positive correlations between vegetation, use of outdoor spaces, and neighborhood social ties. As noted above, most of these studies have been conducted in inner-city public housing projects in Chicago. While the results provide a good indicator of the *direction* of the effect (positive) between social capital and green infrastructure, applying these values to Portland provides low certainty regarding the *size* of the effect. Therefore, based on these studies, it is reasonable to assume that G2G BMPs that increase vegetation and green spaces have a positive influence on neighborhood social ties and social capital in Portland, but the extent of the influence is unknown.

Table 5.3 Summary of Social Capital Effects by BMP

G2G BMP	Applicable	Relationship	Comment
Ecoroofs	Uncertain	Potentially positive	Positive effect if ecoroofs create usable, common green spaces promote social interaction
Green streets	Yes	Increase social capital	Often include trees and increase vegetation, possibly promoting use of outdoor spaces, more walking, more social contacts
Trees: Street	Yes	Increase social capital	Street trees that create and enhance outdoor spaces may promote social interaction
Trees: Yard	Uncertain	Potentially positive	If yard trees are large enough to enhance public outdoor spaces than social interaction and community cohesion may increase.
Invasives removal / revegetation	No	NA	May increase trees and vegetation, but generally in natural areas, not in neighborhoods
Culvert Removal	No	NA	May include revegetation but relatively minor and culvert removal itself is not related to social interactions/social capital
Land Purchase	Uncertain	Potentially positive	Could be applicable if the purchase would result in creation of a new park or usable green space within or near a neighborhood.
Planting in natural areas	No	NA	Increases trees and vegetation but not in urban areas

5.2.3 Crime

The Landscape and Human Health Laboratory's website describes several ways in which vegetation lowers crime:

> "First, greenery helps people to relax and renew, reducing aggression. Second, green spaces bring people together outdoors, increasing surveillance and discouraging criminals. Relatedly, the green and groomed appearance of an apartment building is a cue to criminals that owners and residents care about a property and watch over it and each other" (UI, 2009).

As with social capital, most of the research on vegetation and crime has been conducted in public housing developments in Chicago's inner city. A recent study in Portland, Oregon, however, supports the conclusion that street trees are associated with lower crime rates.

5.2.3.1 Data Sources and Methodology

Two studies provide most of the available data on the effect of trees and vegetation on crime rates:

- Donovan, G. H., currently unpublished research discussed in the following fact sheet: The Economic Benefit of Urban Trees. Friends of Trees, March 30, 2009.
- Kuo, F.E. and W.C. Sullivan, Environment and crime in the inner city: does vegetation reduce crime? Environment and Behavior, 2001. 33(3): p. 343-367.

Kuo's research found that within the same housing development, buildings with high levels of vegetation had 48 percent fewer property crimes and 56 percent fewer violent crimes than buildings with low levels of vegetation. Medium levels of vegetation were associated with 40 percent fewer property crimes and 44%

fewer violent crimes than low levels of vegetation.[8] Vegetation was associated with lower crime rates when the number of units in a building and building height were controlled.

Goeffrey Donovan with the U. S. Forest Service, Pacific Northwest Research Station recently conducted research on 2800 single-family homes in southeast Portland. Preliminary findings indicate that street trees are associated with lower rates of various types of crimes, with the greatest effect on vandalism.[9]

The available studies both show a negative relationship between vegetation and crime, but the extent to which trees reduce crimes varies by type of crime and location of trees (e.g., yard trees with low branches were positively associated with crime in the Portland study). These studies are also limited to residential areas, and do not include commercial or industrial areas. In addition, the results for inner-city public housing projects in Chicago may have limited applicability in Portland. It is reasonable to assume that projects to increase the number of street trees in Portland residential areas are likely to reduce crime rates where the trees are planted. The extent of the reduction is unknown, however, and it is possible that crimes are merely displaced or relocated to other areas of the City.[10]

5.2.3.2 Benefit Estimation and Certainty Level

Kuo's research looked at overall vegetation outside buildings, while Donovan's focused on trees specifically. This research indicates that crime is reduced with increased vegetation in urban areas near buildings, so the metric is likely applicable to trees, green streets, and potentially ecoroofs. It is expected that there is little to no relationship between crime and the other BMPs, because they are typically located in undeveloped or less urban areas. A summary of the relationship between crime and the BMPs is provided in Table 5.4.

Table 5.4 Summary of Crime Reduction Effects by BMP

G2G BMP	Applicable	Relationship/Magnitude	Comment
Ecoroofs	Uncertain	NA	Does increase vegetation in urban areas but not at street level, so effect is not known.
Green streets	Yes	Decrease crime	Often include trees and increase vegetation in residential, commercial, and industrial areas
Trees: Street	Yes	Decrease crime	Street trees in residential, commercial, & industrial areas.
Trees: Yard	Yes	Uncertain.	Effects depend on size and proximity of yard tree to house. Research in Portland indicates that yard trees decrease crime if do not obstruct view of house, but may increase crime if branches obstruct view of house.
Invasives removal / revegetation	No	NA	May increase trees and vegetation, but generally in natural areas
Culvert Removal	No	NA	May include revegetation but relatively minor and culvert removal itself is not related to reduction in crime.
Land Purchase	No	NA	Generally will not increase vegetation (but may preserve it); often undeveloped area.
Planting in natural areas	No	NA	Increases trees and vegetation but not in urban areas

8 Kuo, F.E. and W.C. Sullivan, "Environment and crime in the inner city: does vegetation reduce crime?" Environment and Behavior, 2001. 33(3): p. 343-367.

9 Donovan, G. H. The Economic Benefit of Urban Trees. Friends of Trees, March 30, 2009.

10 Donovan, G. H. The Economic Benefit of Urban Trees. Friends of Trees, March 30, 2009.

5.3 ENVIRONMENTAL EQUITY (LOCATION OF PROJECTS)

In an effort to acknowledge and measure the degree of environmental equity accomplished by the G2G Initiative, the livability subgroup determined that there is community benefit when BMPs are located in underserved neighborhoods such as minority-dominated or low-income neighborhoods. Environmental equity and justice is often considered in terms of avoiding disproportionately high adverse effects on any one racial, ethnic, or socioeconomic group. However, the distribution of positive environmental effects also achieves a goal of environmental equity when underserved populations and other populations receive proportionately equal shares of positive BMPs.

To measure this, a metric has been developed that compares the share of all neighborhoods that qualify as either "low income" or "minority" to the share of underserved neighborhoods that receive G2G BMPs. Calculating this metric will provide information regarding whether G2G BMPs have been equitably distributed across neighborhoods in the City. G2G Initiative mandates determine the locations of BMPs based on opportunities for habitat and hydrologic improvements, and not community characteristics. However, when site selection does occur in underserved neighborhoods, then the share of BMPs in these neighborhoods increases, and this is determined to be a community benefit outside of the primary G2G Initiative goals and objectives.

5.3.1 Data Sources and Methodology

The environmental equity benefit measurement depends on whether the metric is calculated at a value of 1 or greater. If so, then the G2G Initiative provides the community benefit of environmental equity. Individual BMPs that move the metric higher or lower can also be interpreted either as providing, or not providing this additional benefit accordingly.

The overall metric is the average of two similar measures, one for low-income neighborhoods and one for minority neighborhoods. Based on data from the 2000 census available from the Office of Neighborhood Information, City of Portland, there are 110 neighborhoods in the City (ONI, 2009) (These numbers are developed based on Census 2000 data, and should be reviewed again once the 2010 census has been completed.) Of these, 11, or exactly 10 percent have poverty levels of 20 percent or higher. If at least 10 percent of G2G BMPs are located within these 11 neighborhoods, then the environmental equity benefit is being achieved with respect to low income communities.[11]

With respect to minority neighborhoods, there are 13 neighborhoods that have minority populations of more than 40 percent, or in other words have white populations that make up less than 60 percent of the neighborhood population. These 13 neighborhoods represent 12 percent of the 110 neighborhoods in Portland. If at least 12 percent of G2G BMPs are located in these 13 neighborhoods, then the environmental equity benefit is being achieved with respect to minority communities.[12]

The overall environmental equity measure can be calculated as the average of the two measures.[13] For example, if the minority measure of environmental equity is 1.2 and the low income measure of environmental equity is 0.9, then the overall environmental equity measure would be 1.05.

[11] Low Income Measure = (# of G2G projects in minority neighborhoods/# of G2G projects)/0.10.
[12] Minority Measure = (# of G2G projects in minority neighborhoods/# of G2G projects)/0.12.
[13] Overall Environmental Equity Measure = (Minority Measure + Low Income Measure)/2.

5.3.2 Benefit Estimation and Certainty Level

The environmental equity measure can be calculated for each G2G BMP, but are not estimated in this project as it is not yet determined where many of the G2G BMPs will be located. Once the 2010 census is available and G2G BMP locations are determined, the certainty level will be quite high as the demographic data on neighborhood composition in Portland will be very recent.

5.4 ACCESS TO NATURE/GREENNESS

In addition to aesthetics, community cohesion, and environmental equity, there is a related, but additional community livability benefit that is based on the inherent enjoyment to people of being in and near nature (Wolf, 2008). This type of benefit was touched on previously in the health section, as physical health and mental health have been linked to nearness to greenness and nature. Stephen R. Kellert described this phenomenon in a recent keynote address in Portland:

> "the human biological and ecological need for contact with nature... has been increasingly identified as a prerequisite of human physical and mental health and productivity" (Kellert, 2004). (p. 4)

Kellert goes on to describe more than merely physical and mental health maintenance, mentioning studies that identify how greater exposure to nature and natural lighting and ventilation has been linked to improved cognition with greater concentration and memory; higher test scores, improved attendance, and greater teacher satisfaction in schools. Studies have also shown that natural settings are linked to a more restful state of mind that fosters the kind of psycho-physiological activation needed for complex work. Within the expert panel, the concept was determined to be distinct from the other social and community benefits and was given the name "access to nature".

5.4.1 Data Sources and Methodology

One way to measure access to nature might be the number of people living within a certain distance of a natural area. However, many people access nature from their place of employment or commercial areas that they visit, so access to nature that is proximate to places of employment or commercial areas is important and should also be incorporated into the metric. Ultimately, the livability subgroup agreed that the metric should be the number of people exposed to G2G BMPs, and it was determined that general planning numbers could be used for this purpose. That is, in residential neighborhoods, the numbers of pedestrians passing a location can be used to measure the benefit of access to nature of a green BMP at that location (assuming that green BMPs are built into other pedestrian friendly features). This metric has limitations, but was deemed a reasonable proxy for the access to nature benefit that may arise from G2G BMPs.

Research on pedestrian volumes was conducted in 1997 by Moudon et al. from the University of Washington (Moudon, 1997). The authors explored the numbers of pedestrians per hour in similarly dense neighborhoods in Puget Sound, all within a half-mile of a commercial center. In neighborhoods with sidewalks and other pedestrian-friendly features (called "urban" areas), 38 pedestrians were found walking per 1,000 residents living within a half-mile radius of the site. In neighborhoods without sidewalks or lacking in other pedestrian connectivity features (called "suburban"), this number was lower, but still significant at 12 people per hour per 1,000 residents within a half-mile radius. The number of residents ranged from 3,000 to 7,000 people within a half-mile radius (or roughly 0.78 of a square mile).

This approach can be used to measure the benefit of access to nature. However, the calculation of population density used in this paper is fairly complicated, and a simpler approach is recommended. The Moudon et al. paper concludes that over the course of a day (counts were conducted between 11AM and 7PM) there was an average of 257 pedestrians per hour in the areas where sidewalks and pedestrian facilities were available. In areas where pedestrian facilities were not available, the counts averaged 78 pedestrians per hour. If these numbers are multiplied by eight hours of study, the result is 2,056 pedestrians per day in areas conducive to walking, and 624 pedestrians for the areas without sidewalks, etc.

Other data sources include the City of Portland Department of Transportation Pedestrian and Bicycle Count. These data are updated annually, and provide a wide variety of locations within Portland. However, the livability subgroup was not aware of any existing attempts to normalize these data and hence the metrics based on the Puget Sound pedestrian counts are expected to provide a better metric. The data will fall short in terms of the numbers of bicyclists, and people who pass by and enjoy the more natural area in cars.

5.4.2 Benefit Estimation and Certainty Level

Table 5.5 summarizes the applicability of the access to nature benefit by BMP. G2G BMPs that are in areas visible to pedestrians, bicyclists, or even motorists will provide benefits. Areas providing access will likely give even greater benefits. BMPs such as ecoroofs, green streets, and trees that are located in the urban environment will provide benefits to the people living, working, or shopping in the area. Benefits from other BMPs depend on whether they are located in areas that are visible or accessible to people.

The measures of pedestrian volume borrowed from the Seattle area study are appropriate since the areas used in the study are similar to residential areas in Portland. There are several reasons why those numbers might represent an underestimate of exposure to G2G projects, and as well why these might represent an overestimate. The estimates are based on only areas that had a commercial center within a half a mile of the site. Numbers of pedestrians are likely to be lower in areas that do not have a commercial center within half a half mile. Also, the sampling was conducted between June and October, when there are more pedestrians than in the winter months. With these factors in mind, the estimates might be too high for some parts of Portland. However, the numbers of pedestrians could be much too low for Portland because a) the study was conducted over 10 years ago, and pedestrian volumes have been increasing in Portland over the last decade, b) the numbers do not account for bicyclists or people in cars, and c) the numbers are based on an eight-hour period from 11AM to 7PM, although pedestrians are out before 11:00 and after 7:00.

Table 5.5 Summary of Access to Nature Benefits by G2G BMP

G2G BMP	Applicable	Relationship/Magnitude (Per Location)	Comment
Ecoroofs	Yes	Magnitude is dependent on the number of people with views of or access to the ecoroofs.	Increase vegetation in residential, commercial, & industrial areas, but may provide less access to nature if not visible to street pedestrians or traffic, or if not accessible.
Green streets	Yes	2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas.	Increase vegetation in residential, commercial, & industrial areas
Trees	Yes	2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas.	Street trees in residential, commercial, & industrial areas
Invasives removal / revegetation	Uncertain	Uncertain effect	There will be benefit if people perceive that the landscape is more natural, and if the BMP is implemented in visible areas.
Culvert removal	Uncertain	Uncertain effect	Culvert removal will result in additional wildlife and habitat, and benefits will result if the affected streams are visible or accessible to people.
Land purchase	Uncertain	(where applicable) 2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas.	The location will determine the access to nature benefits; if the land purchase is located in areas where it is visible to people or if access is provided there will be benefits..

G2G BMP	Applicable	Relationship/Magnitude (Per Location)	Comment
Planting in natural areas	Uncertain	(where applicable) 2,000 pedestrians/day walkable areas, and 600 pedestrians in less walkable areas.	The location will determine the access to nature benefits; if the natural planting is located in areas where it is visible to people or if access is provided there will be benefits.

S E C T I O N 6

Recommendations and Next Steps

The process of defining and measuring the many benefits of G2G BMPs revealed several areas of research where additional data would be useful. The panel recommends that BES continue monitoring new and ongoing research that could provide additional data or increase the level of certainty associated with the measurements presented in this report. In addition, BES should consider partnering with local researchers to investigate topics where Portland-specific data would clarify the benefits provided by local green infrastructure. Potential research topics include:

- the relationship between greenness and walkability/bikeability;
- trees and social capital in Portland neighborhoods;
- carbon sequestration on local ecoroofs;
- the effect of an ecoroof on neighboring property values (i.e., properties with views of an ecoroof); and
- methods for quantifying access to nature.

BES will also work to assign monetary values to as many of the benefits as possible to provide a common unit for comparing the costs and benefits of G2G BMPs.

The panel further recommends that data on ecosystem services benefits should inform BES decision-making processes, including prioritization and funding of G2G projects and other green infrastructure initiatives. The BES Director and Leadership Team should be familiar with this information so that future projects, both grey and green, can be evaluated in terms of the many types of benefits they provide to the community beyond traditional stormwater management.

BES should further disseminate the data in this report to the City Council and other City of Portland Bureaus to encourage consideration of these benefits whenever infrastructure projects are being planned and evaluated in the City. In addition, these data can inform other relevant City processes and initiatives, such as the global climate change policy formalization, new eco-districts programs, and 20-minute neighborhoods.

To the extent that the report is of interest to other municipalities and researchers, the information should be shared freely. Likewise the research used to inform this report should be maintained in an easy access format and location for ease of use by BES and others in the future. As BES works to promote the benefits of green infrastructure for stormwater management, we can both gain from the research done by others and contribute our own experience and knoweldge to encourage green infrastructure on a broader scale.

SECTION 7

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APPENDIX A

Benefits Table

Table A.1 below provides the benefits information estimated by BES for the hydrology, habitat, and water quality improvements generated by G2G BMPs, while Table A.2 presents the BES original “other benefits” information that was the starting point for this study. The benefits categories identified by BES are the columns of the table, while the rows are the G2G BMPs (described in detail in Section 1.4). The estimated benefits are presented, as well as an indication of the relative magnitude of the expected benefits. One asterisk (*) indicates that the benefits are expected to be relatively small, two asterisks (**) indicates that benefits are expected to be relatively average, and three asterisks (***) indicates that benefits are expected to be relatively large. Benefits are those that are expected to result from implementing the five-year goals for each G2G BMP.

Table A-1 Original BES Benefits Table for Hydrology, Habitat, and Water Quality Improvements

		Hydrology Improvement				Habitat Improvements			Water Quality Improvements	
Action	Grey to Green Five-Year Goals	Slow Stormwater Flows	Recharge Groundwater and Surface Infiltration	Improve Evapo-transpiration	Stormwater Reuse	Preserve Stream Baseflows	Aquatic Habitat	Terrestrial Habitat	Water Temperature Reduction	Pollution Reduction
Ecoroofs	43 acres	** 60% peak flow reduction from 43 acres of roof	NA	*** 27.3 m gal/yr	NA	NA	NA	** 43 acres of habitat	NA	** 95% reduction based on metals
Green streets/ swales	920 Facilities	** 93 % peak flow reduction from 92 acres	*** 68.2 m gal/yr	**1.7 m gal/yr	* 1.0 m gal/yr	***	NA	** 6.3 acres of habitat	*	*** 80% TSS reduction from 92 acres
Trees	33,000 yard trees	*** 10% reduction in flow rates from 536 acres	**2.8 m gal/yr	*** 145.6 m gal/yr	* 11.7 m gal/yr	**	** 26.8 acres of riparian	*** 455.6 acres of "new" habitat	***	**
	50,000 street trees	*** 10% reduction in flow rates from 1104 acres	** 8.8 m gal/yr	*** 299.8 m gal/yr	* 8.9 m gal/yr	**	* 22.1 acres of riparian	*** 1104 acres of habitat	***	**
Invasive Species Removal and Revegetation	Process and code development - Implement invasives EDRR Program and 840 acres of recovered lands	*** 10% reduction in flow rates from 840 acres	**44.5 m gal/yr	** 20.5 m gal/yr	* 8.9 m gal/yr	**	** 126 acres of riparian	*** 840 acres of improved habitat	***	**
Culvert removal	8 culverts in five years	NA	NA	NA	NA	NA	*** >4 miles stream open to passage	* 48.5 acres of riparian	**	NA
Land Purchases	A Total of 2855 acres identified.[14]	*** 419 acres of natural function preserved	*** 419 acres of natural function preserved	*** 419acres of natural function preserved	NA	***	** 21.0 acres preserved riparian	*** 419 acres preserved	**	***

[14] 840 acres are Tier 1, highest priority. To front load the land acquisition efforts and take advantage of existing purchase opportunities, the first five-year period land purchases will be 419 acres

		Hydrology Improvement				Habitat Improvements			Water Quality Improvements	
Action	Grey to Green Five-Year Goals	Slow Stormwater Flows	Recharge Groundwater and Surface Infiltration	Improve Evapo-transpiration	Stormwater Reuse	Preserve Stream Baseflows	Aquatic Habitat	Terrestrial Habitat	Water Temperature Reduction	Pollution Reduction
Planting in Natural Areas	350 acres	*** 10% reduction in flow rates from 350 acres	*** 18.5 m gal/yr	** 8.6 m gal/yr	* 3.7 m gal/yr	**	** 17.5 acres riparian reveg	*** 175 acres improved function	***	**
Ecosystems Services	Process and development	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table A-2 Original BES Benefits Table for Other Benefits

		Other Benefits and Factors				
Action	Grey to Green Five-Year Goals	Community Livability	Air Quality	Energy Efficiency	Carbon Sequestration	Cost Effectiveness (roofs)
Ecoroofs	43 acres	* 43 acres of "garden", visual relief	*** Air temp reduction	*** Insulation, absorption of solar energy	* Increased biomass	*** Life cycle cost less than convention roof
Green streets/ swales	920 Facilities	*** 6.3 acres planted area, visual relief	*** Air temp reduction	** Reduction in stormwater pumping and treatment as combined sewage	** Increased biomass	** Life cycle cost less than conventional pumping, piping and treatment systems
Trees	33,000 yard trees	*** 536 acres canopy, visual relief, 19% increase in associated property values	** Up to 20 deg F lower air temperatures	*** 27% reductions in cooling and 15% reductions in heating energy	*** 215 tons carbon per year	*** Very low costs relative to conventional methods
	50,000 street trees	*** 1104 acres canopy, visual relief, 19% increase in adjacent property values			*** 325 tons carbon per year	*** Very low costs relative to conventional methods
Invasive Species Removal and Revegetation	Process and code development - Implement invasives EDRR Program and 840 acres of recovered lands	*** Replace 840 acres of invasives and weeds (aesthetic)	***	**	*	**
Culvert removal	8 culverts in five years	** Return native fish to 4 miles of stream for observation, recreation, aesthetic	NA	NA	NA	*
Land Purchases	A Total of 2855 acres identified.[15]	*** 419 acres of open space preserved, recreation	***	**	*** 1362 tons/yr carbon seq preserved	**
Planting in Natural Areas	350 acres	***	***	**	*	**

[15] 840 acres are Tier 1, highest priority. To front load the land acquiring efforts and take advantage of existing purchase opportunities, the first five-year period land purchases will be 419 acres.

APPENDIX B

Expert Panel Process

The scope of the "other benefits" provided by G2G BMPs is broad, encompassing effects on community livability, air quality, energy consumption, carbon sequestration, and human health. To ensure that all of these effects were adequately considered in this process, BES convened an expert panel from a wide spectrum of fields and organizations to contribute to the process of defining and quantifying benefits. Representatives from government, academia, development, and non-profit organizations were asked to participate in two panel-wide workshops as well as smaller subgroup meetings. Two contractors were hired to assist with the process. ENTRIX provided technical expertise, developed the approach in conjunction with BES, and assisted with identifying experts. ENTRIX also led the development of this report utilizing data gathered in workshops and subgroup meetings, information developed by panel experts and BES staff, as well as supplemental research conducted for this report. EnviroIssues served as process coordinator, assisted with identifying and contacting experts, and facilitated and led the expert panel workshops.

The first panel workshop was held on June 23, 2009. At this workshop, BES gave an overview of the G2G program and informed panel members of the purpose, specific objectives, and timeline of the expert panel process. BES also described each G2G BMP and the data already developed quantifying the hydrologic, habitat, and water quality benefits. ENTRIX provided an overview of the benefits table structure and the steps in the benefits quantification process, including defining benefits categories, identifying metrics (representative measures of benefit), and conducting research to quantify or qualify to the extent possible the benefit expected from G2G BMPs. It was emphasized to panel members that quantification of benefits was very desirable, but it was recognized that for some benefits only qualitative description of benefits would be possible.

As a starting point, ENTRIX and BES worked together prior to the initial workshop to propose "other benefits" categories and possible metrics for the panel's consideration (see Table B.1). The benefit categories were also aggregated into three subgroupings: Health, Energy, and Community Livability. Based on the expertise and interest of each panel member, panelists were assigned to one (or more) of the subgroups (see Section 1.3 for a complete listing acknowledging panel members by subgroup).

Table B.1 Proposed Benefit Categories and Metrics

Proposed Benefit Categories	Possible Metrics	Subgroup
Health	Walkability, obesity, respiratory illness, temperature, airborne particulate matter, nitrogen oxide	Health
Energy Use	Thermal insulation, building energy use, solar reflectivity, stormwater pump/treatment energy use, car use	Energy
Carbon/Greenhouse Gas	Reduced carbon emissions, carbon sequestered, biomass	Energy
Amenity/Aesthetics	Property values, green space, natural/native environmental aesthetic, noise level	Community Livability
Recreation	Visitation, use	Community Livability
Community Cohesion/Crime	Household participation in G2G BMPs, crime, walkability	Community Livability

Certain economic benefits of the BMPs were excluded from this process, including reduced infrastructure cost and increased tourism-related activity. It is expected that these benefits will be quantified in a later process that may express all benefits from G2G in terms of their dollar value.

Each subgroup was asked to refine the benefit categories, identify appropriate metrics to measure and estimate the benefits in each category, provide relevant data and references, and consider the level of certainty associated with the benefits estimates. The subgroups met independently over the summer to complete these tasks. A final workshop for the entire expert panel was held on August 25, 2009 to present and discuss each group's results. Recommendations were developed regarding additional research needed to increase certainty of benefits measurements and to address data gaps.

DEFINING BENEFIT CATEGORIES

As noted above, ENTRIX worked with BES to develop the proposed benefits categories in Table B.1. Each subgroup refined their categories based on relevancy to the G2G Initiative, available data (feasibility of measurement), and ability to capture the most important and relevant benefits. Defining benefits categories was very simple for some subgroups, while it was a more complex process for others. The process was most straightforward for the energy subgroup, which settled quickly on the two proposed categories of energy use and carbon. The process was fairly straightforward for the health subgroup, but much more complicated for the livability group.

The health subgroup defined two benefit categories. Air quality improvement was quickly identified as the first benefit category. Vegetation enhances air quality, which in turn enhances health. Other types of benefits that the subgroup wanted to capture are effects of vegetation and green spaces on physical and mental health. This is an emerging field of public health research, with causal links less well defined, and with potential overlap in the mechanisms improving mental and physical health. After a review of the data and the literature, the group determined that the best way to capture these benefits was a general category of increased greenness.

The community livability subgroup defined four benefit categories. This subgroup also focused on how increased greenness generates benefits, but in the context of improved livability. The task of defining distinct benefit categories in this context was a challenge because of the overlapping nature of many livability benefits. For example, greenness has been linked to walking in the community, and has also been linked to community cohesion, yet these effects are related (and overlap with health benefits). Another challenge was that many potential benefit categories are difficult to measure due to lack of research relevant to the G2G BMPs. After considering a wide variety of potential community livability benefits, the subgroup determined that four categories would adequately cover the range of benefits: amenity value/aesthetics; community cohesion; environmental equity; and a separate category for improvement in overall access or exposure to nature in the urban environment. The final benefits categories are reflected in Table 2.1, and are described in further detail in Sections 3, 4, and 5.

MEASUREMENT OBJECTIVES AND PROCESS

For each benefit category, the expert panel was asked to identify metrics (the variables to measure to estimate benefits) that are meaningful, representative, and could be applied across the BMPs to the extent possible. The objective of each metric is to provide a measure of the level of benefit provided by each BMP; the metrics are not intended to provide an exhaustive review of all possible benefits that may be generated. Because of the diversity of BMPs in the G2G initiative, it was recognized that some metrics would not apply to all of the BMPs but may still be valuable in measuring certain important benefits. The time scale involved in realizing benefits also varies across BMPs, and some BMPs have been studied much more extensively than others.

Where possible, metrics were selected that show a direct effect. For example, air quality may change directly as a result of implementing certain BMPs as measured by levels of particulate matter in the air. In some cases, it was possible and meaningful to include indirect effects as well. For example, lower particulate levels may reduce respiratory illness, an indirect result of certain BMPs.

Once metrics were selected, expert panel members were asked to provide data, references, and resources to quantify the benefits of the BMP. Because of the variances in available data for different BMPs and metrics, the panel was also asked to provide a level of confidence for each estimate. To the extent possible, the process was designed to produce quantitative data, although ultimately the benefits of certain BMPs were captured more effectively with qualitative information.

REPORT COMPILATION

The data and input provided by expert panel members was then analyzed and compiled as presented in this report by ENTRIX and BES. The expert panel members, as well as several outside reviewers provided comment on the report.

APPENDIX C

June 23, 2009 Workshop Notes

Ecosystems Services Benefits Quantification Expert Panel

Portland Building, 2nd Floor, Room B
1120 SW 5th Ave., Portland, OR 97201

June 23, 2009 • 8:30am – 3:30pm
Workshop 1 Summary

Purpose of the Meeting

The Bureau of Environmental Services (BES) convened an expert panel from a wide spectrum of fields including government, academia, development, and NGO/nonprofits to review work already done by the City in identifying and defining ecosystem benefits and associated metrics attributed to Grey to Green (G2G) Best Management Practices (BMPs). These BMPs include facilities and practices such as green streets, planting trees, ecoroofs, and natural area revegetation. This was the first of two workshops. The purpose of this workshop was to:

- provide participants with the context within which the ecosystems services benefits quantification process was initiated
- explain the methodology that will be used
- separate participants into subcommittee groups aligned with benefits categories
- begin identifying metrics that can be applied to each category
- plan future subcommittee work

A second workshop is tentatively scheduled for August 25, 2009. Subcommittees will hold meetings in the interim to further work in their benefits category area. A final report will be produced that describes the findings of the Expert Panel's efforts.

Meeting Guidelines

Due to the brief project timeline, this group did not undergo a formal chartering process. Expert Panel members represent diverse backgrounds and levels of expertise. The facilitator requested that during group discussions participants maintain conversation at a level in which everyone can follow and participate. Discussions not directly related to the workshop's purpose and topics will be recorded in a 'parking lot' list to be addressed at a later date.

Expert Panel Composition

The Ecosystems Services Benefits Quantification Expert Panel (*Expert Panel*) is comprised of the participants who committed to attend Expert Panel meetings, as well as members who have committed a 'partial' amount of time or have requested to be included on the Expert Panel's distribution list. These individuals are reflected on the Expert Panel Contact List. In addition, a number of individuals have been identified that possess specialized expertise and may be called upon to contribute to the Expert Panel's work on an as-needed basis. The Expert Panel was initiated and is managed by BES staff and is supported by technical consultant, ENTRIX, Inc. and process consultant, EnviroIssues.

The Context of Grey to Green

Within the last fifteen years, BES has begun incorporating green infrastructure into their programs and the momentum to do more has increased along with a rising national interest in sustainability. BES has shown in scientific terms, through habitat, water quality, and hydrology improvements, that better outcomes can be achieved through green infrastructure. These outcomes are also popular, work more effectively, and are less expensive.

As density, along with impervious surfaces, increases and infrastructure investments are delayed due to the CSO mandate, the timing is right to increase green infrastructure implementation. In the Hawthorne district, basement sewer backup was a major problem and the proposed 'grey' approach would have been very expensive. Through a mix of green and grey infrastructure, BES was able to save $58 million. This is an impressive accomplishment, but there is a need to demonstrate other benefits of green infrastructure to continue to promote its use.

Former City Commissioner Sam Adams launched the Grey to Green (G2G) initiative as an 'on the ground' implementation of watershed management plan principles. The initiative provides $50 million over a five-year period to make up the market difference of what is affordable under the current rate structure. This amount will not be enough to achieve all G2G goals, so partnerships will be essential to the success of the program. The G2G initiative specific implementation targets include:

- Add 43 acres of ecoroofs
- Construct 920 new Green Street facilities
- Plant 33,000 yard trees and 50,000 street trees
- Step up the fight against invasive weeds
- Replace 8 culverts that block fish passage
- Purchase 419 acres of high priority natural areas

About the BMPs

Ecoroofs are lightweight, vegetated roof systems. The City of Portland currently has 12,000 acres of rooftop. Twenty of those acres are currently ecoroofs, ten of which are intensive ecoroofs.

Green Streets are stormwater management facilities in the public right-of-way often consisting of planters, porous pavement, swales, or vegetated infiltration basins. These often exist along curb extensions, bike paths, and transportation improvements and manage, on average, 1/10 of an acre of stormwater collection area. There are approximately 700 facilities installed citywide.

Street and Yard Trees contribute to the City's urban canopy. Fully planted, the City could support 525,000 trees. The current amount is 236,000, or 45% of capacity. The City offers free permits for property owners to plant street trees in the City right-of-way, but has not implemented its own program in decades. G2G proposes planting 50,000 street trees and 30,000 yard trees to bring the City up to 52% of its capacity. Friends of Trees, a local non-profit is currently under contract with BES to support this effort.

Invasive Species Removal is handled under two different BES programs. The "Protect the Best" program protects the best ecological assets on public land from invasion of invasives like ivy and garlic mustard. These include areas such as Forest Park, Powell Butte, and Mt. Tabor. The Early Detection, Rapid Response (EDRR) program takes a 'spot fire' approach to catching particularly invasive species early. Through the EDRR program, 840 acres will be recovered.

Land Acquisition identifies lands that are of the highest quality or pose the highest risk for hazards such as flooding or land slide. High quality lands include natural park areas, properties contiguous to other protected areas, springs, and headwaters. High risk areas include steep slopes or other areas that, if developed, may likely necessitate future mitigations. Purchasing these lands could make up the cost of future mitigations. These areas may be converted into passive recreation or trails, but may also remain as general acquisition or restoration properties.

Culvert Removal involves dozens of culverts that have been identified as barriers to native fish within the City, mostly in the outer southeast and Crystal Springs. Under G2G, the main goal is to focus efforts in one subwatershed, where full benefits can be achieved and lead to spawning salmon above the barriers. This BMP is highly leveraged at $2 million for the removal of eight culverts.

G2G Benefits Table

The G2G Benefits table originated out of a request from former City Commissioner Sam Adams to show the benefits of the G2G initiative in a quantitative way. The table represents the first effort to capture this information and provides a structural base to expand its content through additional information and expertise.

BES' primary responsibility is administering the stormwater and sanitary systems in the City of Portland. Therefore, the table demonstrates a more solid understanding of the benefits of green infrastructure in terms of habitat, hydrology, and water quality. These categories continue to evolve and may need some refining, but the focus of the Expert Panel is to develop metrics for the 'Other Benefits' portion of the table. 'Other Benefits' are values that the public finds desirable, but are not currently being accounted for in planning infrastructure improvements. 'Other Benefit' categories include:

- health
- energy use
- carbon/greenhouse gas
- amenity/aesthetics
- recreation
- community cohesion/crime prevention

Like the watershed health benefits, already on the table, each 'Other Benefit' category will need to be assigned a metric that can be carried through each of the BMP categories. Once a metric has been chosen, each BMP row will need a unit of measurement that corresponds to the chosen metric. These metrics will help demonstrate the benefits of the BMPs through quantifying what may already be known intuitively. It was suggested that a column should be added that states who the benefactors of these services are. This may help to identify potential program partners.

How to Select Metrics

Metrics should be chosen for their ability to be meaningful, representative, and applied across the BMPs. Each row (BMP) may have a different pathway in terms of how it relates to the metric. Determining the best metric will involve finding a common link among how they are applied across the BMPs. Due to the nature of this process, there will inevitably be some inconsistencies and variances. These may include that:

- A metric may not apply to all of the BMPs. This is acceptable for this point in the process, as it should not deter subcommittees from selecting the best indicator or proxy for their benefits category.

- Timescales may vary across metrics. For example, acquiring land that prevents development on an area with a steep slope may have a more immediate effect than planting a tree that will take years to mature. If a timescale can be qualified, it should be added to the exercise.
- Data sources may not hold equal weight. Some metrics may rely on government data that has been collected for decades, whereas others may best represented by a new study that has been recently published.

Metrics will primarily show a direct effect, unless there is data that can link a metric further. For example, under the 'Health' category, if data only exists for the direct cause, such as levels of particulate matter in the air, then the metric stops there. If there is data to support a further metric, such as asthma rates being directly related to particulate matter, then it will more meaningful and utilize the Expert Panel's expertise. At the very least, subcommittees should identify the natural phenomenon at work. It is possible that going any further may be impossible if data does not yet exist to support any further conclusion.

In future subcommittee meetings, the groups will be tasked with coming up with actual estimates for their metric to determine what each BMP provides. After that, a level of confidence will be given to the assigned metric value that will take into account some of the variations and inconsistencies mentioned above. Although this process may be somewhat awkward at times, it is essential to move beyond qualitative data to demonstrate the merits of incorporating BMPs.

Additional individuals have been identified as resources that may be able to provide expertise, if not present within the current Expert Panel. In addition, two participants identified additional resources that may be useful. Eric Wentland stated that there was a study done by consultant, Eco Northwest, at least five years ago that contained related information. Bobby Cochran mentioned that the Willamette Partnership is using NRCS' ounting on the Environment for a process they are conducting that has similar objectives.

Subcommittee Assignments

Energy/Carbon	Health	Community Livability
Debbie Beck*	Daniela Cargill	Bobby Cochran
Steve Fancher	Linda Dobson	Ryan Durocher
Allen Lee	Geof Donovan*	Paige Goganian
Tom Liptan	Patricia Huback	Mike Houck
Mike Weedall	Jennifer Karps	Roberta Jortner
Eric Wentland	Dave Kliewer	Jennifer Karps
	Chris Lowe	Deb Lev
	Monica Russell	Noelwah Netusil
		Heather Randol*
		Dan Vizzini

*indicates subcommittee contact

Subcommittee participants received a handout containing questions to guide them through the process of selecting metrics and units. They were asked to address each of the questions on the handout and arrive at some metrics that make sense. The general process followed the following steps:

1. Identify the connections between each BMP and benefits in subcommittee area (unconstrained brainstorm)
2. Identify commonalities/patterns associated with the benefits/outcomes in subcommittee area.

3. Identify one to two, and not more than three, metrics in subcommittee area
4. List strengths/weaknesses of each selected metric
5. Identify what units may work for each cell in subcommittee area
6. Create a work plan of next steps, questions, and logistics for gathering information and future meetings

Each subcommittee generated a write-up of their proceedings and they are attached to this document.

Use of the Final Report

The main purpose of the final report is for it to be used in BES Systems Planning and Alternative Analysis for Prioritization. The report will be coupled with flow management analyses and become part of infrastructure decision-making considerations. During the Expert Panel workshop, participants identified potential additional uses that included the report being used to inform:

- BES urban watershed planning efforts
- BES compliance reporting for regulatory permits
- Bureau of Planning and Sustainability efforts
- City of Portland Comprehensive Plan updates (Fall 2009)
- City Council policy decisions
- Mayoral efforts to promote green infrastructure
- Water Environment Research Foundation (WERF)
- American Society of Landscape Architects (ASLA) and other professional organizations

Next Steps

- The next full Expert Panel meeting is tentatively scheduled for August 25, 2009.
- As subcommittees continue their work, they should keep the Project Management team informed of their progress. Contact EnviroIssues (Julie Wilson and Lisa Timmerman) for administrative issues and ENTRIX (Barbara Wyse and Gretchen Greene) for technical issues.

APPENDIX D

Subgroup Meeting Notes

HEALTH SUB GROUP NOTES

Health Subgroup Notes: July 22, 2009

Particulate Matter

- How's it going with data gathering?
  - *Patricia and Monica presented DEQ data on overall particulate matter emissions by county (tons per year) and also monitoring data on the levels of PM 10 at monitoring stations throughout the city.*
  - *There is very little correlation between the overall emissions levels and the PM10 levels recorded throughout the city.*
  - *DEQ also has data from a model that examined PM10 levels around the city – this model uses data from 2005.*
  - *Models indicate how much pm is taken out of the air by trees (can be extrapolated to other vegetation types), but harder to estimate effect of vegetation on pm10 levels.*
  - *Environmental Health Tracking Database effort is trying to correlate respiratory illness with air quality levels – Oregon is a handful of states participating. There are no results yet but should be available in a few years.*
- How's it going with data analysis?
  - *Geof has ideas re how to link Portland canopy (actual #s of %canopy cover and % evergreen) to particular matter. Assume that homogenous reduction across the city to estimate city PM10 levels.*
  - *Geof will also link this PM10 level to conclusions re health status of Portlanders using dose response functions for pm10. At low levels we're dealing with, should be linear response curve.*
  - *Geof will also ask Nowak how to extrapolate tree data to other BMPs – ecoroofs and green streets and possibly open space;*
  - *Jennifer K will provide Geof inputs re existing Portland canopy for Geoff's above work*
- NEXT STEPS: *Jennifer and Geof will get as far as they can with the above work by the next meeting*
- OTHER:
  - *Geof reported that he will likely have Portland-specific information re birth outcome effects of trees by mid-August. (Possible 3rd metric for physical health.)*

"Greenness" Metric

- How's it going with data gathering? *Chris reported that a lot of literature cites connection between greenness and physical and emotional health, direct (e.g.: feel better when looking at green) and indirect (e.g.: makes you more likely to exercise); Almost all data based on survey. A lot of literature uses a loose definition of greenness which makes it difficult to define and use a directly transferable metric, but does allow us some flexibility in what we include and count as "greenness". There is a lot of literature on the effect of greenness on walking behavior. Literature shows that health effects are greater in lower income neighborhoods.*
- How's it going with data analysis? *(no data analysis yet, but Chris and Geof indicated that it would be relatively easy to draw conclusions re projected changes in walking behavior as greenness improves in Portland, IF we can get some numbers for how much greenness is expected to improve. The group then discussed possible GIS approaches for doing such an analysis in the "Tabor to River" basin.*
- NEXT STEPS: *Daniela will check with BES GIS staff re their availability to do the analysis predicted to take 2-4 weeks of someone's time. Geof will work with Daniela to refine the work order, assuming resources are available.*
  Outline of work:
  1. *Canopy analysis for each house in the basin*
  2. *Network analysis (Geof will help define factors)to open space RESULT = "as is" greenness analysis (Need to define what we're measuring here – % green in distance to open space, to other walking destinations such as libraries, stores, transit, etc)*
  3. *Place G2G greenstreet facilities and trees in basin*
  4. *Do canopy analysis for each house*
  5. *Do network analysis to open space. RESULT = projected change in greenness as measured by distance to open space.*

  There was a discussion about what we are actually measuring. Could we gain as much by simply measuring the overall change in the level of greenness in the area as indicated by canopy cover instead of conducting the network analysis. Also, could have a different metric that shows the % of population within a certain distance of green space and how the implementation of G2G changes this statistic.

Mental Health Metric

- <u>How's it going with data gathering?</u> *The literature Chris gathered on mental health suggests that greenness has an overall subjective effect on well being and mental health, primarily through survey research. There are some studies that have looked at effects on aggression (crime too), depression, ADD, and cognitive function.*
- <u>How's it going with data analysis?</u> <u>*Difficult to quantify effects, and difficult to tie to the Grey to Green BMP's.*</u>
- <u>NEXT STEPS:</u> *Chris will continue to look for studies linking mental health and greenness, but the group determined that this will be a qualitative write-up on the literature rather than a quantitative metric with measured benefits.*

Health Subgroup Notes 8/5/09

<u>Air Quality and Health</u>

Geoff presented the data he's been able to collect from Dave Nowak's model. This data estimates the total emissions absorbed by trees and shrubs in Portland, for smog, pm10, carbon monoxide, and sulfur dioxide. Geof will see if he can also get pm2.5 data. Geoff also presented the EPA data for the dose-response curves for mortality, morbidity (illness), and work loss days. The group discussed that benefits will likely be measured for the following BMP's: trees, ecoroofs, and potentially green streets. Preservation benefits can also be potentially measured for land purchases. We determined that benefits should be presented in an annual average (so small benefits in early years when vegetation is first planted will be averaged across the years when vegetation is mature and more air pollutants are removed). We will also try to calculate total air pollutant removal over the course of the project life.

Action Items:

- **Geoff** is contacting Dave Nowak to determine what the unit of measurement is in the model so that we can convert the figures to a per unit basis (e.g. canopy cover or leaf area or number of trees).
- **Geoff** is also checking on the level of detail in Dave's model to see if we should provide him species level data or not and if the model assumes some kind of growth curve. He will follow up with **Jennifer** who will provide appropriate level of detail on street trees and green streets, and see if Dave will re-run model to get the change in emissions expected for G2G programs.
- **Heather** is looking up data on ecoroof pollutant removal from ecoroof cost benefit study. (Heather – thanks for following up on this; I got your email).
- Need to convert tons of pollutants to ambient concentration levels – **Patricia/ Monica** can you do this?
- Apply the EPA dose /response curve and determine which health effect would be the most effective metric. **Geoff** are you going to do this?
- Document the analysis and data sources. **Geoff** can you do this?

<u>Greenness Metric and Walkability/Mental Health</u>

Matt and Heather reported that there are several greenness metrics available that quantitatively measure the level of greenness, but that there are very few studies tying these metrics to walkability or mental health. They did find one study that connected BMI to the greenness measure of "Normalized Difference Vegetation Index". The group is still planning to discuss the walkability / mental health benefits qualitatively. Chris has volunteered to document the research he has conducted in these areas.

ENERGY SUBGROUP NOTES

Energy Meeting Notes July 5, 2009

<u>Overview</u>

We are currently in the throes of calculation! We discussed that each of us will work to finalize our quantitative estimates and provide them to the group in spreadsheet form for 'peer review'. We also discussed the need to document our sources and methodology for the estimates. Barbara will send out a template for documenting both the quantitative as well as the qualitative aspects of our work.

<u>Energy Use</u>

Stormwater pumping

- **Tom** is calculating reduced energy use for ecoroofs and street trees. Need to check with Jennifer regarding life of tree, deciduous/evergreen, and average size. Benefits will be calculated as average annual as well as for life of tree.
- **Steve** is calculating reduced energy use for green streets.
- **Tom and Steve** will share their calculations with the group, and **Allen** will use their figures to estimate carbon emission reductions. He will use the 2008 average electricity price to convert the $0.002 / gallon figure back to kWh.
- **Steve** will qualitatively discuss stormwater pumping as it relates to land purchases, planting in natural areas, and invasive/revegetation. There is no identified relationship with culvert removal.

Insulation / Shade

- **Seth and Debbie** will work to quantify the direct insulation/shading effects on building energy use of ecoroofs and green streets.
- **Barbara** will work to quantify the direct energy use effects of tree shading.

Heat Island Effect

- **Seth and Debbie** will work to quantify the temperature reduction and energy use reduction associated with reduced heat island effect from ecoroofs, green streets, trees, and land purchase.
- **Seth** sent the following: EPA website has an entire compendium on Urban Heat Island impacts including carbon sequestration. http://www.epa.gov/heatisland/resources/compendium.htm

Carbon

Carbon Emissions Reduction

- **Allen** will calculate the reduced carbon emissions by converting the figures from others into kWh and then into carbon.
- **Allen** will need the 2008 $/kWh to convert the stormwater value of $0.002.gallon to kWh.
- **Seth** sent the following Dept. of Energy link that has data on average electricity rates for April 2009 for residential, commercial, and industrial: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=OR. The DOE website has much more data on average electricity rates.
- **Allen** collected the following information on **energy to GHG conversions:**
    - PGE:[16]
      Electricity: 0.524 lbs CO2 per kWh
      Natural Gas: 13.446 lbs CO2 per therm
    - Pacific Power:[17]
      Electricity: Hermiston, OR Natural Gas Plant
      118.9 lb CO2 per MMBtu, 1MMBTU=293.1 kWh => 0.406 lbs CO2 per kWh Natural Gas
    - Vehicle Fuel Emissions: (Note: these are of the liquid fuel only, NOT life cycle emissions)[18]
      Gasoline: 19.4 lbs CO2 per gallon
      Diesel: 22.2 lbs CO2 per gallon

Carbon Sequestration

- **Allen** will calculate the reduced carbon emissions by converting the figures from others into kWh and then into carbon based on carbon protocols for counting sequestration.
- According to **Jennifer Karps**, street/yard trees often have a short average lifespan, but that it is safe to assume that they will be replanted if/when they die.

Energy/Carbon Subgroup Meeting: July 22, 2009

Overview

We went through the tables below to determine which cells we were going to quantify and who was going to quantify the energy / carbon benefits. We determined three primary pathways for reduced energy use: reduced energy associated with stormwater volume reduction, decreased building energy use from direct insulation/shade from BMP's, and reduced

[16] http://www.pge.com/about/environment/calculator/assumptions.shtml
[17] http://www.pacificorp.com/File/File70930.pdf, 2005
[18] http://www.epa.gov/OMS/climate/420f05001.htm

building energy use from reduced heat island effect. We noted that it is important on the reduced heat island effect to report the reduction in temperature as this is something people can relate to, and that it may be difficult to actually quantify energy savings from the temperature reduction.

Carbon benefits will be based on a conversion from reduced energy use in kWh to reduced tonnes CO2 equivalents emitted as well as long-term sequestration benefits. Carbon benefits will be calculated as they are in the emerging carbon market protocols.

Methodological Notes

- Reduced stormwater will be converted to energy benefits using the BES figures of $.0002 / gallon of stormwater.
- Ecoroofs direct insulation effect (in excess of standard insulation) has been modeled at PSU – Dave Sailor.
- Energy used in project construction should be included in project cost – so it is already accounted for on the cost side of the ledger. We will still qualitatively note the potential energy use of these projects, but will not quantify it for this reason and for the relatively small amount that it represents.

Next Steps

The tables below summarize what cells we are quantifying and who is responsible for each quantified piece.

Key:
X: Measurable benefits
+: We know how to quantify benefits

		Energy Savings KWh/Year		
G2G Program	Unit	*Stormwater Volume Reduction*	*Insulation /Shade*	*Heat Island Effect*
Ecoroofs	kWh/sq ft	X+ (Tom)	X (Debbie?)	X+ (Debbie?)
Green Streets	kWh/sq ft	X+ (Steve)	N/A	X+ (Debbie?)
Trees	kWh/tree	X+ (Tom)	X+ (Geof/Barbara)	X+ (Debbie?)
Invasive Removal/Reveg		Qualitative Discussion of Change in Gas Use and Land Use		
Culvert Removal				
Land Purchase		Qualitative	N/A	Qualitative
Planting in Natural Areas		Qualitative	N/A	Qualitative

		Carbon Tonne CO2 Equiv	
G2G Program	Unit	Reduced GHG Emissions	Sequestration
Ecoroofs	Tonne /sq ft	X+ (Alan)	Alan to check on carbon protocol, likely N/A or qualitative
Green Streets	Tonne /sq ft	X+ (Alan)	
Trees	Tonne/tree	X+ (Alan)	X+ (Alan)
Invasive Removal/Reveg		Small impact – Qualitative Discussion.	Alan to check on carbon protocol, likely N/A or qualitative
Culvert Removal			
Land Purchase	Tonne/acre		X+
Planting in Natural Areas			Small Impact - Qualitative Discussion

LIVABILTY SUBGROUP NOTES

Notes for Community Livability Subgroup Meeting 7/21/09

Overview of Work to Date

Heather recapped the work to date – including review of the metrics proposed at the first workshop (access to nature, property value, visitation, walkability, and number events/participants). She also mentioned her conversations with the

BES program managers about the connections between their work and these metrics (documented in a table distributed via email to the subgroup), and noted that it was difficult to make connections between the metrics and several of the programs, particularly invasives/ revegetation and culvert removals. Regarding the number of events/participants metrics she also noted that there are very few events sponsored for natural areas. She also said that there is relatively little access to revegetation / invasive removal areas.

General Questions / Comments

- How do we measure the benefits? And are we trying to just measure the benefits of the G2G program?
  - Our purpose is to develop metrics to measure the types of benefits that are derived from the types of BMP's in G2G. Once we have metrics that can measure the benefits per unit of BMP, then we can move to the accounting phase in which the benefits for the current G2G programs can be measured (i.e. unit of BMP * benefit per unit).
  - This exercise is focused on the benefits of the G2G BMP's, so no other BMP's are included. However, the hope is that this work will be useful and generalizable for measuring benefits of other City programs.
- As we move through this process, we may need to redefine benefits categories based on the measurable benefits of the BMP's
- The Lents study was noted as providing potentially useful measures of ecosystem services.
- Two elements that Bobby Cochran suggested be included are social justice and crime. Crime benefits in particular are often tied strongly to funding resources. Social justice and crime reduction were added to the table.
- One difficulty with measuring benefits is that the level of increased benefit may change depending on how much green infrastructure is already available (i.e. the benefit increase may not be linear). For example, the incremental benefit associated with increased access to nature may diminish when the overall level of access increases.
  - It may be useful to use percentage increase, or increase in the number of people within a certain distance from a natural area to take into account current level and incremental increase in benefit.
- Do we measure both public community benefits as well as private benefits (such as those to building owners)?
  - Yes – we want to measure all types of benefits.

Access to Nature

- Access to nature does not necessarily mean physical access to nature – there is an indirect benefit that is derived because of views and wildlife that people see even if they do not have access to the site.
- Additionally, some revegetation sites have visitation – Mike Houck noted that he has taken approximately 600 people on field trips to Oaks Bottom, with one focus being the history and changes due to revegetation. There are also school groups who visit the site. However, tying the number of trips tied to revegetation effort may be difficult.
- Access to nature involves an education component.
- Oaks Bottom is a special case, as is the Brownwoods area (off Springwater Corridor). These are areas high visibility areas, and are not representative of most revegetation sites which do not have access. Need to be able to accurately represent benefits for the diversity of site types – some of which have direct, access benefits and some of which only have indirect benefits.
- There is an intrinsic value for the health of the watershed that has value for people.
- One way to measure access to nature may be number of people living within a certain distance of a natural area.
- Many people access nature from their place of employment also – so access to nature that is proximate to places of employment is important and should perhaps be incorporated also into the metric
- There is the issue of how to measure the benefit of protecting existing natural areas that may otherwise be degraded or developed.
- Bottom line – it is a struggle to get a good metric for access to nature but people agree it is important.

Equity / Social Justice

- Many people voiced their belief that equity and social justice is an important issue
- Access to nature and equity/social justice are linked, but there was some concern to link it too much. They are separate benefits.
- Several people thought there was a lack of connection between Green Streets and the equity atlas

- Portland City Parks has been conducting a similar analysis that can substitute for the Atlas. It includes connectivity regarding whether you can actually walk to the different locations. You can select different criteria to see what area is serviced within a specific walking distance.
- There are standards for access to parks and open space.

- Some actions (such as acquiring lands high in the watershed to restore ecosystem function) that are physically distant from neighborhoods may have no connection to social justice
- G2G and Parks doing a lot of joint acquisitions. There are multiple objectives for land acquisition.
    - G2G focus is to protect their infrastructure investments while benefiting the watershed.
    - Parks objectives are to improve connectivity, enhance wildlife, while having a joint interest with G2G for protecting and enhancing special status habitats. Parks are getting involved in school yard plantings.

Crime

- Geof Donovan has done research on trees and crime
- Could overlay tree canopy and crime statistics in Portland to see how correlated they are
- Be cautious of putting crime and equity/social justice too close together –don't want to link them in any way (even perhaps in where they are listed in the table).

Property Values

- There are many great studies on how property values increase in locations near green infrastructure and open space
- These hedonic studies measure the change in property value due to the green infrastructure and are not focused on the total price of the property.
- Concern about double counting as property values imbed a lot of different types of values – including walkability, access to nature, crime, etc.
- Portland has a medium to high level of open space
- John Russell, downtown developer is a good resource
- Ecoroofs can increase property value if visible to neighbors / building dweller
- Noelwah has done work on value of different types of green space vegetation including the non-marginal effects on property values of tree canopy. There is a lot of work on NDVI (measure of greenness). Metro has created a more refined measure of greenness.
- We need to consider the benefits of improved quality of open space also (revegetation, invasive removal), not just quantity as measured by proximity.
    - John Loomis did a study of improved property values related to restoring riparian corridors
- There is also a potential connection between wildlife and property values
    - Geof Donovan has done work in this area

Visitors/Tourism

- Open space and parks attracts visitors and businesses
- It is tied to the growth of the city
- Travel Oregon and TIC may have data on visitors
- This economic benefit may be measured separately – need to confirm with Daniela

Walkability

- Green streets can increase walkability by slowing traffic
- There are two relationships b/w walkability and green infrastructure: connectivity and quality of experience
    - Is there an increase in the propensity to walk b/c of quality? Is there literature on this?
- Paige is familiar with studies on how property value increases based on reduction in auto trips due to proximity to parks/shops/etc within walking distance.
- City is developing walkability index that is more sophisticated than walkscore in terms of connectivity (20 minute neighborhood project). Roberta may be a good contact on this.
    - Question is, how do these BMP's change the walkscore?
- There are a lot of bike counts done throughout the city. Could these be related to green infrastructure?
    - Perhaps more related to where there are bike paths
    - Jennifer Dill at PSU has studied where people ride their bikes in Portland to see what influenced where they chose to ride
    - Anecdotally, many people like to ride their bike on streets with trees.

Participation in Number of Events

- Tom Liptan at BES has number of participants on ecoroof tours
- Parks can provide lists of Friends Groups
    - These groups have a lot to do with demographics and whether there is a community leader

MOVING FORWARD

- We have several people experts in the rows: Steve (greenstreets), Ryan (invasives/reveg), Jennifer (trees) that can offer perspective and answer questions.

G2G Community Livability Expert Subgroup: September 5, 2009

We reviewed the process of where we are and where we're going in terms of determining the types of benefits of G2G programs and potential metrics for measuring these benefits. Starting with the suggested benefits categories of amenity/aesthetics, recreation, and community cohesion/crime, we have worked our way through several proposed metrics, including measure of property values, greenness, number of visitors to Portland and to G2G facilities, neighborhood participation, walkability, and crime rates. Many of these categories are overlapping, and many are difficult to measure. It appears that property values in particular may capture many of these benefits, and is one of the most quantifiable metrics that we have. Crime may also be quantifiable, particularly based on Geof Donovan's study, which he summarized for us. Greenness, as measured by such indices as Normalized Difference Vegetation Index (NDVI), can also be quantified but may be less useful for our purposes based on research conducted by Matt Wood.

We also discussed social justice/equity, property values, and general findings on access to nature/greenness.

Crime

Geof Donovan summarized his ongoing research in Portland on the effects of trees and other variables on residential crime. Studying such types of crime as theft, burglary, robbery, vandalism, and motor vehicle theft, in his preliminary results Geof has found that street trees are a statistically significant crime deterrent while yard trees are a statistically significant crime attractor. Interpreting and further analyzing the results, Geof has found that it appears that yard trees may increase household crime by blocking visibility with low hanging branches. Street trees, on the other hand, appear to have an effect that is the exact opposite of the "broken window" effect. Street trees may send the message that a house is well cared for and therefore deter crime, just as a house with broken windows may indicate that it is not well cared for and therefore may attract more crime. Geof noted that there are few other rigorous studies that indicate a relationship between crime and vegetation, but that it may be possible to extrapolate from the effects of trees to other types of vegetation in the street right of way.

Greenness

Matt Wood summarized his findings regarding measures of greenness in the literature. He has found that NDVI is the index that has been most commonly used in past studies, and that it is based on remote sensing and is a measure of photosynthetic production. It is unclear whether the index differentiates between types of vegetation (e.g. grass versus multistory canopy). Matt also noted that there are different, more refined measures of greenness that are being developed, including the Enhanced Vegetation Index. There are some studies that link these measures of greenness to walkability and body mass index (BMI), but there seem to be very few of them. In the general discussion about these indices, it was noted that the usefulness of these indices may be limited given the relatively small impact that G2G programs would have the indices on a city-wide scale, or even a neighborhood scale. It was also noted that these indices are fairly esoteric and may be less comprehensible to a lay audience unless they could be put in percentage terms. The group also noted that there are so many other factors that affect walkability and other benefits that the effect of greenness will likely vary based on location (i.e. some areas of the west side has lots of greenness, but low walkability). It was noted, however, that street trees and green streets are located only in an improved right of way that includes sidewalks.

Social Justice

Gretchen and Bobby proposed an approach to social justice that would be a simple measure for each G2G program of whether implementation is in a low income or minority neighborhood. This would identify whether funding for G2G programs is equitably distributed. It was noted that it is very difficult to define social justice / equity, or to measure if the G2G programs are assisting in achieving social justice. It is difficult to determine what improves social conditions. It was also noted that it is important to be careful of terminology; one alternative proposed term could be "underserved population". It was noted that this metric may differ from the others as it can only be evaluated after the G2G program location is proposed, which differs from the other benefit categories that may be more broadly applied regardless of location (though these also may confer different benefits depending on site location). A question was raised regarding the weight that may be applied to this versus other G2G goals. It was discussed that this type of weighting of different types of benefits may be developed later, but that it is important to include this as another piece of information to consider in the decision-making process.

Ecotourism

Heather reported that data on ecotourism has been difficult to obtain. Suggestions for further research include Greg Newland at Travel Oregon and Washington County Visitors Association.

Property Values

Noelwah and Geoff have conducted several studies in Portland on the effects of natural areas and trees on property values that can be applied to some of the BMP's. It was also noted that there may be some literature from Europe on the effects of ecoroofs on property values. Tom Liptan may have relevant information from ecoroof conference proceedings.

Access to Nature/Greenness

Mike reported that there are several employers in Washington County who could be sited as a case study who have chosen location based on environmental amenities and whose employees have invested time in site restoration in the area around the office. There may be anecdotal information from the owners on the importance of access to nature and the productivity of the employees, as well as higher lease price information that employers have paid.

Paige reported that she has been finding that most of the literature emphasizes that there is value in exposure and proximity to greenness. She also noted that there is an impact when a building or an environment resonates with people and they form a connection to it. She suggested that one measure of this connection could be turnover rates (either home ownership or leases).

APPENDIX E

August 25, 2009 Workshop Notes

Ecosystems Services Benefits Quantification Expert Panel

Portland Building, 2nd Floor, Room B
1120 SW 5th Ave., Portland, OR 97201

August 25, 2009 • 8:30am – 12:00pm
Workshop 2 Summary

Purpose of the Meeting

The Bureau of Environmental Services (BES) has been working to identify and measure the ecosystem benefits of its Grey to Green (G2G) Best Management Practices (BMPs). BES has previously focused on estimating the hydrology, habitat, and water quality benefits associated with these BMPs, which include facilities and practices such as green streets, planting trees, ecoroofs, invasives removal, land purchases, and natural area revegetation. To estimate the "other benefits" of the G2G program, including such benefits as increased community livability, health effects, and energy/carbon savings, BES convened an expert panel from a wide spectrum of fields and organizations including government, academia, development, and NGO/nonprofits. The purpose of this expert panel is to identify metrics and use these metrics to measure the "other" ecosystem benefits of the G2G BMPs.

This was the second of two workshops involving the full expert panel. Participants were previously assigned to one of three subcommittees – health, community/livability, and energy/carbon. Each held two subcommittee meetings in between the two workshop meetings and many expert panel members researched and gathered information for their subcommittee topic. The purpose of the second workshop was to:

- update the expert panel on its progress to date and describe any work remaining to fulfill the panel's purpose.
- present an overview of the work completed by each subcommittee along with a brief opportunity for discussion.
- break up into the respective subcommittees to identify remaining tasks and a timeline for completion.

This was the final formal meeting of this group. This process will culminate with a report documenting the panel's findings. A draft report will be distributed to panel members for review in early October, with a final report to be completed by late October or early November.

Meeting Attendees

Debbie Beck, *Portland State University*
Bobby Cochran, *Clean Water Services*
Paige Goganian, *City of Hillsboro - Planning*
Mike Houck, *Urban Greenspaces Institute*
Jennifer Karps, *Portland Parks and Recreation*
Danielle Kolp, *The Cadmus Group*
Deb Lev, *Portland Planning*
Chris Lowe, *Portland State University*
Heather Randol, *Portland BES*
Dennis Wilde, *Gerding Edlen*
Barbara Wyse, *Entrix*
Daniela Cargill, *Portland BES*
Steve Fancher, *City of Gresham*
Gretchen Greene, *Entrix*
Cynthia Kan, *The Cadmus Group*
Dave Kliewer, *Portland BES*
Allen Lee, *The Cadmus Group*
Tom Liptan, *Portland BES*
Seth Moody, *Portland State University*
Lisa Timmerman, *EnviroIssues*
Julie Wilson, *EnviroIssues*

Progress to Date

Each subcommittee held two meetings between the two workshops to assist in gathering research to support their selected measures and metrics. Based on the work completed by the subcommittees, each cell in the “Other Benefits” section of the original G2G Benefits Table was categorized as follows:

- *Quantified Benefit*: The subcommittee was able to come up with a quantifiable value for the BMP (or for the type of BMP) according to their selected measures and metrics.
- *Descriptive Benefit*: Through their research, the subcommittee was able to support a positive or negative association between the BMP for their selected measure or metric, but they were not able to quantify the relationship.
- *Generally Not Applicable:* The subcommittee could not definitively identify a quantitative or descriptive relationship. These cells represent areas where there is not yet a clear correlation and supporting data for the given BMP and benefit category. This category does not mean that a cell is less of a priority than others. It does indicate areas that may need additional research.

Subcommittee Progress Reports

Each subcommittee provided an overview of the information they had gathered between the two workshops. The following section describes the reports that each subcommittee delivered, generally categorized by the approach they took, their findings, challenges they faced, and any feedback provided by the larger group following their report. For more specific details and numbers generated by the subcommittees, please refer to the Benefits Table attached to the end of this document. Additional detail will also be provided in the final report.

Community/Livability

Approach

The subcommittee divided their category into four measures with accompanying metrics as follows:

- Access to Nature - # of people affected
- Amenity/Aesthetics – property values
- Community Cohesion – crime/social capital
- Environmental Equity – low income/minorities affected

The metrics were chosen for their ability to quantify benefits of as many of the BMPs as possible. Property value, for example, was chosen as a metric because two of the Expert Panel members (Geoff Donovan and Noelwah Netusil) are nationally known modelers of this information and there is a large, existing body of data.

Findings

Consistently across the measures, the largest amount of data was available for trees. Panel member Geoff Donovan has done some studies showing that trees tend to lower crime rates. The group also used a study from panel member Noelwah Netusil that showed that properties within 1,500 ft. of a park preserved as a natural area increased property values by $14,798. A study completed in Seattle showed that properties located near green streets, swales, or an area where a culvert had been removed had 3-5.5% higher property values.

The group is still working on a useful metric to show the number of people who could be expected to directly benefit from BMPs. A preliminary approach is to estimate the number of people affected by using data on the number of people living within a ¼ mile radius of a BMP (based on population density in the City). The ¼ mile radius statistic is based on transportation planning literature, which often uses ¼ mile as the distance people are willing to walk.

The group determined that the Crime/Social Capital measure may need to be split because there are much firmer numbers for crime than social capital. The group reviewed a study by Kuo in Chicago showed that housing developments with vegetation outside yielded 52% lower crime rates. Panel member Geoff Donovan recently completed a study of crime in SE Portland and found that street trees are related to lower crime rates. For yard trees, the results varied. If a low yard tree canopy was present, crime results were mixed. Study findings indicated that yard trees with low hanging branches are associated with higher crime rates, with the hypothesized cause being reduced visibility.

Challenges

- The subcommittee did not find any studies that related property value to ecoroofs. They found a study about rates for hotel rooms with a view of an ecoroof, but this did not directly relate to the property value metric.
- Calculating the value of trees can be difficult because there is not a linear relationship between property values and trees. Property values rise greatly with the first trees, then rises less with additional trees (diminishing returns), until at some point too many trees may cause a decrease in property value because of such factors as reduced light or visibility.

Feedback from the Group

- Ecoroofs could potentially be linked to property value because they have been shown to have a longer life than conventional roofs. This may be covered in the life cycle / economic considerations that will be included in the next phase of the study.
- Dennis Wilde of Gerding Edlen suggested that ecoroofs add value to their projects, but that they could only describe that anecdotally for now.
- It was a noted that people will focus on a number estimating how many people will be affected by BMPs, and that this should be given careful consideration.

Health

Approach

The subcommittee split the health category into benefits derived from air quality and those derived from 'greenness' (increased vegetative cover).

<u>Air Quality</u>

The subcommittee measured the effects of vegetation on air quality in Portland by using data from US Forest Service researcher Dave Nowak. Nowak's model estimates the total volume in metric tonnes of air pollutants such as PM10, nitrogen dioxide, and sulfur dioxide removed from the air by trees in Portland. Combined with existing DEQ air quality monitoring data for Multnomah County for PM10, the total tonnage from Nowak's model was translated into a reduced concentration per cubic meter. To estimate the benefit to health from this pollutant reduction, the estimated PM10 concentration reduction was analyzed using the EPA's Dose Response Curves linking PM10 levels to physical health.

'Greenness'

The 'greenness' measure was split into physical and mental health categories, with some overlap occurring between the two. For physical health, walkability was used as a metric. The idea is that health could be improved by green features if they encourage more people to get out and walk. The literature also suggests that green features such as those that would be increased through many of the G2G programs would decrease the severity or symptoms of mental illnesses or disorders.

Findings

The preliminary results for air quality indicate a statistically significant decrease for asthma and other respiratory symptoms from all trees in Portland. No results have been extrapolated for specific G2G programs. The 'greenness' measure shows positive correlations to increased mental and physical health, but remains difficult to quantify.

The 'walkability' metric remains a qualitative measure because it is difficult to examine in isolation and relatively little literature exists on the impact of G2G BMPs on walkability. Other interacting factors such as perceptions of safety and quality of sidewalks may skew results. The subcommittee also considered that walkability may be dependent upon what stage of life a person is in. Focusing solely on walkability may miss correlations of children playing and other forms of outdoor recreation that improve physical health that the literature indicates increases with increased greenness.

Many studies have also shown positive mental health relationships between 'greenness' and these same activities. A study by Taylor showed that children that played in greener settings had less severe ADD symptoms. Another study by Kuo showed that those living in impoverished conditions with access to nature assessed their own stress levels as lower and claimed to be more able to cope than those without access.

Challenges

- The data used for air quality combines data for Multnomah County and Portland.
- The model used (Dave Nowak's) is based off of trees and there is a lot of uncertainty about how it could apply to the other BMPs. Also, Dave Nowak's model estimates effects of all vegetation in Portland and it may not be possible to extrapolate from this data the effects of additional vegetation due to G2G program elements.
- It is believed (but will be verified) that Dave Nowak's model does not account for decreased air pollution due to reduced temperatures from trees (a reduction in the heat island effect) or the production of pollution from maintenance of the tree canopy.
- Invasives Removal and Culvert Mitigation were difficult to characterize using the selected metrics.
- There is relatively little literature pertaining to the connection between health and BMPs other than trees.

Feedback from the Group

- Seth Moody mentioned that Dave Sailor may have some helpful information specific to ozone.
- Pilot studies to monitor the effects of existing green infrastructure would be a good place to direct future research.
- Biking and walking associations could be helpful in monitoring and retrieving information specific to the 'greenness' measure. It's no mistake that popular biking corridors (like Salmon St.) are also highly vegetated. They keep users cool in the summer and shield them from wind and rain in the winter.
- Tom Liptan referenced a study done by Tillaly (sp?) that shows a comparison of the effects of native versus non-native vegetation.
- Mike Houck recommended looking for studies that measured blood pressure in 'green' environments. There may be some studies completed in hospitals.

Energy/Carbon

Approach

This subcommittee looked at measures of energy savings and carbon reduction. Three mechanisms were identified relative to the BMPs that could result in energy savings. These included:

- Stormwater volume reduction
- Insulation and shade (direct savings)
- Heat Island Effect (indirect savings)

Some of these were then able to be translated into kilowatt hour savings by BMP.

Carbon was examined according to sequestration and additional carbon reductions that could be achieved through reductions in greenhouse gases. The subcommittee calculations focused only on benefits because it assumed that any energy costs of the BMPs could be accounted for in the life cycle costs of the projects.

Findings

To estimate energy savings from stormwater volume reduction, the subcommittee first estimated the amount of stormwater that ecoroofs, green streets and trees were able to retain. No estimates were developed for invasive/revegetation and culvert removal BMPs, but a qualitative association may be possible with land purchase and planting in natural areas.

For insulation, the subcommittee looked at R-values to characterize the insulating properties of ecoroofs. This information was gathered based on a new thesis produced last year. The subcommittee was able to come up with a preliminary range, but further examination will be required.

The subcommittee is also reviewing new research on the heat island effect, much of which is being conducted at PSU, to estimate the effects of the BMPs on temperature. Heat island effects from green streets could potentially be equated with the shade value from ecoroofs because they have similar properties, but the subcommittee was unable to locate any information that describes plant density within green streets. A leaf area index will help measure the microshade qualities and effects on the heat island of both of these BMPs.

The subcommittee reviewed protocols, case studies, and tools for quantifying and reporting carbon sequestration and carbon reductions. Some of the resources located included (with any drawbacks noted):

- The World Resource Institute provides a protocol for carbon sequestration that required a lot of detail to quantify. The structure was difficult to apply to the BMPs and much more information would have to be obtained.
- The California Climate Action Registry provides a greenhouse gas calculator. The subgroup is planning to follow the California Climate Action Registry protocols for carbon calculations.
- Healthy Roofs for Green Cities is a Canadian organization that had some information, but it was oriented more towards owners/developers and did not lead to any underlying metrics.
- The US Forest Service has produced the STRATUM tool to quantify street tree sequestration benefits.

Challenges

- Calculating stormwater volume reduction produces varying results depending on which model is used and data assumptions. For example, stormwater reduction from trees varies based on the assumed size of the trees planted.
- Transpiration is not currently included in the stormwater volume reduction calculations.
- For the carbon greenhouse gas categories, the subcommittee noted a lot of inconsistent reporting of carbon vs. carbon dioxide and tons vs. metric tonnes. The subcommittee is using metric tonnes of Carbon for consistency.
- To apply carbon sequestration to green streets, more information is needed on the plant biomass above and below ground to get a range that can be applied to any calculations.

Feedback from the Group

Jennifer Karps stated that data in the Portland tree canopy study may more accurately reflect current conditions for use in estimating benefits from trees.

Additional Discussion

Throughout the workshop some additional discussions and themes arose. These included:

- The characteristics of land to be purchased by BES as a BMP is not clearly defined. Without some standard definition, it is difficult to quantify the effect that this BMP will have. A better understanding of the existing and future use and hydrology of this land needs to be considered.
- The size of an 'average' tree used to make calculations in this process varied. Using an 'average' tree for calculations may not reflect Portland's current tree canopy or trends toward planting smaller trees.
- Each Grey to Green BMP should be clearly described so that all metrics calculations and evaluations are based on the same set of assumptions.
- A peer review of the findings of this panel may add credibility to the process. At the very least, those whose research was included should have an opportunity to review and determine whether their literature was properly interpreted. The project management team encouraged the subcommittees to use some of their breakout time to identify appropriate candidates for peer review.
- Some BMPs were more easily quantified than others. This process should be cautious about signaling that a BMP that is easily quantified does not necessarily translate to that BMP being the highest priority. Funding should not just be steered toward the BMPs where quantification was possible.
- Panel members were concerned about losing access to and maintaining the resources posted to the project web page. The resources will be published in the final report. There is also a possibility that they could be moved to another location on Portland Online to allow continued access for this and other City processes, and/or to allow public access to the links and resources the project team identified. A CD with resource documents could also be provided with the final report.
- The introduction to the report should provide context for this project by describing the other watershed objectives and metrics that have been evaluated previously (i.e., hydrology, habitat, and water quality improvements).
- The final report should include information about how this information can be applied beyond Grey to Green, such as its potential relevance to other City Bureaus.

Next Steps

The final report of the Ecosystem Services Benefits Quantification Expert Panel will be published by early November. The final report will be used to inform:

- The director of the Bureau of Environmental Services
- City Council
- The City global warming policy formalization
- The new Eco-districts program

A draft report will be distributed to panel members for review in early October, with a final report to be completed by late October or early November.

BES will likely have funds to continue some of this work in the next fiscal year. Following the publication of the final report, additional work may include attaching monetary values to the quantification of benefits and identifying areas of future research, which may potentially include BES conducting their own research.

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