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A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds

Final Report

Prepared for:

Howard M. Neukrug, Director, Office of Watersheds,
City of Philadelphia Water Department
under contract to Camp Dresser and McKee

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Objectives

The City of Philadelphia Water Department (PWD) is considering a wide array of options for controlling Combined Sewer Overflow (CSO) events in its four relevant watershed areas. The options range from traditional infrastructure-based approaches (e.g., storage tunnels) to more innovative "green infrastructure" approaches based largely on Low Impact Development (LID) elements (e.g., tree planting, permeable pavement, green roofs).

PWD is especially interested in gaining a more complete understanding of the Triple Bottom Line (TBL) implications of the green and traditional infrastructure approaches in terms of their respective ability to provide environmental, social, public health, and other values. Accordingly, this report provides a TBL-oriented benefit-cost assessment of the CSO control alternatives under consideration by PWD. The focus here is on the benefits and external costs of the alternatives. Ultimately, the TBL benefit results from this report, and the engineering cost information from Camp, Dresser and McKee (CDM), will be combined to provide insights as to the estimated net benefits of the alternatives.

Key Findings

The key finding of this TBL assessment is that the LID-based green infrastructure approaches provide a wide array of important environmental and social benefits to the community, and that these benefits are not generally provided by the more traditional alternatives. Tables S.1 and S.2 provide a summary of the numeric findings for two of the CSO control options under consideration: the 50% LID, or green infrastructure option [meaning runoff from 50% of impervious surface in the City of Philadelphia (the City) is managed through green infrastructure], and the 30' Tunnel option (a system of storage tunnels with an effective diameter of 30 ft, serving all watersheds). These options were chosen to demonstrate the difference in net benefits between green and traditional infrastructure. The reporting of these results is not intended to indicate that a final PWD decision will be based on these two alternatives.

The results shown below reflect benefits (and external costs) accrued over the 40-year study period (from 2010 to 2049). Table S.1 describes the outcomes in terms of the physical outcomes obtained, and the second table provides the estimated monetary value for these outcomes, in present value terms.

Table S.1. City-wide natural unit benefits of key CSO options: Cumulative through 2049[a]

Benefit categories	50% LID option	30' Tunnel option[b]
Additional creekside recreational user days	247,524,281	
Additional non-creekside recreational user days	101,738,547	
Reduction in number of heat-related fatalities	196	
Annual willingness to pay (WTP) per household for water quality and aquatic habitat improvements[c]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	193	
Green collar jobs (job years)	15,266	
Change in particulate matter ($PM_{2.5}$) due to increased trees ($\mu g/m^3$)	0.01569	
Change in seasonal ozone due to increased trees (ppb)	0.04248	
Electricity savings due to cooling effect of trees (kWh)	369,739,725	
Natural gas savings due to cooling effect of trees (kBtu)	599,199,846	
Fuel used (vehicles for construction and operation and maintenance) (gallons)	493,387	1,132,409
Sulfur dioxide (SO_2) emissions (metric tons)	(1,530)[d]	1,452
Nitrogen oxides (NO_x) emissions (metric tons)	(38)	6,356,083
Carbon dioxide (CO_2) emissions (metric tons)	(1,091,433)	347,970
Vehicle delay from construction and maintenance (hours of delay)	346,883	796,597

a. The 50% LID and 30' Tunnel options were chosen as example alternatives to illustrate the differences between green and traditional infrastructure approaches. This does not imply that a final decision has been made by PWD regarding the implementation of these options.
b. 28' Tunnel option in Delaware River Watershed.
c. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.
d. Parentheses indicate negative values.

Relevant TBL Benefit Categories

A summary of the key benefit (and external costs) categories included in this TBL assessment is provided below. Most of these benefits accrue only with the LID-oriented green infrastructure options, and not under the traditional infrastructure alternatives.

Recreation. Under the LID-based options, streamside recreational opportunities will be increased as a result of stream restoration and riparian buffer improvements. Recreation will also improve in non-creekside parts of the City due to the general increase in vegetated and treed acreage in the City. These recreational benefits are not anticipated under the traditional infrastructure approaches.

Table S.2. City-wide present value benefits of key CSO options: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics/property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality/aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvements from trees	$131.0	
Energy savings/usage	$33.7	$(2.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)	$(13.4)
Total	**$2,846.4**	**$122.0**

a. 28' Tunnel option in Delaware River Watershed.

Increased Community Aesthetics, Reflected in Higher Property Values. Trees and plants improve urban aesthetics and community livability and studies show that property values are higher when trees and other vegetation are present.

Heat Stress Reduction. Green infrastructure (trees, green roofs, and bio-retention areas) creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air. This cooling effect will be sufficient to reduce heat stress-related fatalities in the City during extreme heat wave events.

Water Quality and Aquatic Ecosystem Improvements. The traditional infrastructure options (e.g., plant expansions, tunnels) are aimed at reducing the number of overflow episodes, but do little to directly improve the physical riparian area environment (i.e., riparian and aquatic ecosystems and habitat areas) or otherwise enhance living resources in many of the City's watershed environments. In contrast, the LID options, in conjunction with the related watershed restoration efforts, are expected to generate important improvements to these living natural resources.

Wetland Creation and Enhancement. The watershed restoration and related efforts, as associated with the LID options, are expected to create or enhance over 190 acres of wetlands in the relevant watersheds. These added and enhanced wetland acres will provide a range of services in the urban area watersheds.

Poverty Reduction from Local Green Jobs. Specialized labor is required for construction of conventional stormwater management solutions (e.g., boring, tunneling). Such skilled laborers might typically be already employed in the construction field. Green infrastructure creates the opportunity to hire local unskilled – and otherwise unemployed – laborers for landscaping and restoration activities. Thus the benefits of providing these local green jobs include the avoided costs of social services that the City would otherwise provide on behalf of the same people if they remained unemployed.

Energy Savings and Carbon Footprint Reduction. Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In addition, diverting stormwater from wastewater collection, conveyance, and treatment systems reduces the amount of energy needed to pump and treat the water. Reduced energy demands in buildings, and increased carbon sequestration by added vegetation, result in a lower carbon footprint (reduced CO_2 emissions).

Air Quality Improvement. Trees and vegetation also improve air quality by filtering some airborne pollutants (e.g., particulate matter and ozone). Likewise, reduced energy consumption results in decreased emissions (e.g., SO_2 and NO_x) from power generation facilities. These air quality improvements can reduce the incidence and severity of respiratory illness.

Construction- and Maintenance-Related Disruption. All of the CSO options will result in some level of disruption due to construction and/or program activities. Social costs of disruption can include traffic delays, limited access to places of business, increased noise and pollution, and other inconveniences. Under all of the CSO alternatives, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia; however the level of disruption will be considerably less for the LID options than many of the traditional infrastructure alternatives.

1. Introduction

1.1 Background

There are numerous ways of managing stormwater runoff and combined sewer overflow (CSO) events in urban areas. These include traditional engineering approaches that rely largely on physical infrastructure such as large-scale concrete collection and storage systems (e.g., excavating and building large diameter tunnels), and pumping collected stormwater to wastewater treatment plants for treatment and discharge. Alternatively, there are more “natural” and environmentally friendly approaches that rely more on “green infrastructure,” or Low Impact Development (LID) techniques, to help divert, store, and promote infiltration of stormwaters so that they help restore and enhance natural systems rather than overload traditional wastewater collection and treatment facilities. There are various possible levels and combinations of the traditional and green approaches that can be considered.

Both the traditional and green infrastructure approaches to stormwater and CSO management can be very expensive to retrofit within older urban areas (e.g., costing several billion dollars for a city like Philadelphia). Both approaches can also generate important environmental, social, and other benefits to local watersheds and urban-area communities. However, the green infrastructure, LID-oriented approaches may generate a broader and more valuable array of environmental, public health, and social benefits than do traditional CSO control strategies. In order to gain a clearer appreciation of which option (or mix of approaches) may be most valuable to a community, it is important to assess the types and levels of benefits associated with the alternative approaches. These benefits can then be compared to the costs of each option, so that community leaders can discern which approach will yield the largest net benefit to the community (where net benefits refer to present value benefits minus present value costs).

1.2 Objectives

The Philadelphia Water Department (PWD) currently is giving serious consideration to a wide array of options for controlling CSO events. PWD is especially interested in gaining a more complete understanding of the Triple Bottom Line (TBL) implications of green infrastructure approaches, and of more traditional approaches, in terms of their respective environmental, social, and other values. PWD, in concert with its engineering support contractor – Camp, Dresser and McKee (CDM) – retained Stratus Consulting to evaluate the benefits and external costs (i.e., costs beyond engineering cost estimates for building and operating the various control options) associated with a number of alternative approaches for controlling CSO events in the City of Philadelphia (the City).

Accordingly, this report provides a TBL-oriented benefit-cost assessment of the CSO control alternatives under consideration by PWD. The focus here is on the benefits and external costs of the alternatives. CDM is developing a separate report to describe the engineering design and performance aspects – and engineering cost estimates – for the alternatives. Ultimately, the TBL benefit results from this report, and the engineering cost information from CDM, will be combined to provide insights as to the estimated net benefits of the alternatives.

Throughout this report, we refer to the green infrastructure CSO control options as LID-based approaches. We categorize the different options based on different levels of implementation (e.g., the 50% LID option would manage runoff from 50% of impervious surfaces in Philadelphia through green infrastructure). Green infrastructure and LID are used interchangeably throughout the following chapters and appendices.

We also refer to the traditional infrastructure options according to different levels of implementation. For example, throughout the report we draw upon the "30' Tunnel" option as an example alternative. This option includes a system of storage tunnels serving all watersheds with an effective diameter of 30 ft. Alternative tunneling options (e.g., 15', 20', 25', and 35' options), are also being evaluated by PWD and the impacts of all alternatives are examined here.

1.3 Report Organization

This report is structured as follows:

- First, this main portion of the report provides a brief overview of the four PWD watershed areas addressed by the policy options, as well as abbreviated descriptions of the 16 CSO control options being considered for each area. More detailed descriptions of the watersheds and CSO control options are provided in the main body of the PWD Long Term CSO Control Plan Update (LTCPU).

- Second, a general description is provided of the data and methods used to conduct our TBL-oriented benefit-cost assessment of the alternatives. Also provided is an overview of the types of benefits and external costs we address within this assessment.

- Third, more detailed descriptions are offered of the estimated levels of benefits (and external costs) for each major benefit-cost category. An overview of the methods, data, and limitations associated with these estimates is also provided. (Detailed category-specific appendices, described below, furnish additional detail on the methods, data, findings, and limitations of the analysis for each type of benefit or external cost).

- Fourth, summaries are provided of the benefit estimates for two of the prominent CSO control options under consideration, aggregated across the four watershed areas. These summaries thus provide a city-wide overview of the physical and economic magnitude of benefits (and external costs) for two highlighted CSO control alternatives. The two highlighted CSO control options are the LID-50% option (reflecting a green infrastructure approach), and the 30' Tunnel option (reflecting a more traditional infrastructure approach).

- Fifth, a suite of detailed tables are provided that indicate watershed-specific estimates for each benefit and external cost category, for each CSO control option evaluated.

- Sixth, the key uncertainties inherent in this type of TBL-oriented benefit-cost analysis are discussed, and the results of several sensitivity analyses are provided to provide insights as to the level of stability of the estimates to alternative input values and assumptions.

The main body of this report is then followed by a series of detailed technical appendices – one for each benefit or external cost category assessed. These appendices describe the methods, data, findings, and caveats relevant to each endpoint, and also contain relevant reference citations. The appendices correspond to the following categories of assessed impacts:

- Appendix A: Recreational use and values (both creekside and non-creekside)
- Appendix B: Property values, as enhanced by the LID options
- Appendix C: Heat stress and related premature fatalities avoided
- Appendix D: Water quality and aquatic habitat enhancements and values
- Appendix E: Wetland enhancement and creation
- Appendix F: Poverty reduction benefits of local green infrastructure jobs
- Appendix G: Energy usage and related changes in carbon and other emissions
- Appendix H: Air quality pollutant removal from added vegetation
- Appendix I: Construction- and maintenance-related disruption impacts.

2. Relevant Watersheds and CSO Control Options

PWD's CSO program area covers about 40,500 acres (63 square miles) within the City. The boundaries of the CSO area fall within the watersheds of Tacony-Frankford Creek, Cobbs Creek, the Lower Schuylkill River, and the tidal portion of the Delaware River (Delaware Direct Watershed). The City's CSO program is managed on a watershed-basis and our analysis of CSO control options includes the evaluation of management alternatives in each of the four CSO watersheds.

The following sections provide a brief description of each CSO watershed and outlines the different CSO control options being considered by PWD.

2.1 Philadelphia's CSO Watersheds

The Tookany/Tacony-Frankford Watershed

The Tookany/Tacony-Frankford Watershed encompasses approximately 20,000 acres, or 29 square miles, within the north central portion of Philadelphia County and the southeastern portion of Montgomery County. The creek is referred to as Tookany Creek until it enters Philadelphia County at Cheltenham Avenue. It is then called Tacony Creek from the Montgomery County border until it meets with the historical Wingohocking Creek in Juniata Park. The section of stream from Juniata Park to the Delaware River is referred to as Frankford Creek.

The hydrology of the Tacony-Frankford system is highly modified. Most of the tributary system of Tacony Creek has been converted into sewers. Below what is now Juniata Park, the Tacony joins with buried tributaries to form Frankford Creek. In order to deal with flooding associated with large influxes of stormwater, the Frankford Creek was channelized and straightened in concrete a number of years ago. The concrete channel prevents interaction between Frankford Creek and the groundwater system and eliminates streambed habitat needed to support aquatic life. The area surrounding Frankford Creek is highly industrialized and much of the creek is inaccessible.

The Philadelphia County portion of the watershed accounts for about 62% (12,200 acres) of total watershed land area, and PWD's CSO program area covers almost all of this. The population within this part of the watershed is approximately 285,000, which results in an average population density of about 23 persons per acre. There are about 6.3 miles of stream along Tacony-Frankford Creek targeted for improvements under the different CSO control options (mainstem creek).

Cobbs Creek Watershed

Cobbs Creek is a subwatershed of the larger Darby-Cobbs Watershed, which encompasses approximately 80 square miles of land that drain to the mouth of Darby Creek or below, to its confluence with the Delaware Estuary. Cobbs Creek drains approximately 14,500 acres or 27% of the total Darby-Cobbs Watershed area. The upper portions and headwaters of Cobbs Creek, including East and West Branch Indian Creek, contain portions of Philadelphia, Montgomery, and Delaware Counties. The lower portion of Cobbs Creek Watershed, including the lower mainstem and Naylors Run, drain parts of Philadelphia and Delaware Counties. Cobbs Creek discharges to Darby Creek.

The Philadelphia County portion of the Cobbs Creek Watershed is about 3,600 acres, and falls almost entirely within PWD’s CSO program area. This area encompasses about 11.5 miles of stream, including about 8.2 miles of mainstem creek and 3.3 miles of major tributaries. The population of the Philadelphia County portion of the watershed is about 107,000 (U.S. Census Bureau, 2000), which yields a population density of almost 30 persons per acre. Similar to the Tacony-Frankford Watershed, Cobbs Creek is very urbanized and its hydrologic system has been highly modified.

Lower Schuylkill River Watershed

The Schuylkill River Watershed includes portions of 11 counties, and encompasses an area of approximately 2,000 square miles. The river travels approximately 130 miles from its headwaters at Tuscarora Springs in Schuylkill County to its mouth at the Delaware River in Philadelphia. The Schuylkill River is the largest tributary to the Delaware River and is a major contributor to the Delaware Estuary.

The Philadelphia County portion of the Schuylkill River Watershed is approximately 23,000 acres. About half of this area falls within PWD’s CSO area, which includes the tidal portion of the Schuylkill River, or the approximately 7 miles of river upstream of the confluence with the Delaware River.

Much of the land outside of the Schuylkill River CSO area is characterized by large open space areas and recreational amenities (e.g., East and West Fairmount Parks and Boathouse row). However, in the lower portion of the watershed, which coincides with the CSO boundaries, there is a significant amount of industrial land uses.

Within the CSO area, there are numerous active and inactive rail lines directly adjacent to the river, including the large and active East Side Yard for CSX Transportation Corporation (CSXT). Several major road corridors also run adjacent to and through the river, including I-95,

I-76 (Schuylkill Expressway), I-676, Route 291/Passyunk Avenue, Grays Ferry Avenue, University Avenue, South Street, Walnut Street, Chestnut Street, and Market Street.

The population of the Philadelphia County portion of the Lower Schuylkill River Watershed is about 353,000 (U.S. Census Bureau, 2000), which yields a population density of about 16 persons per acre, on average. The majority of residents (about 82%) live within the CSO area, where population density is almost 30 persons per acre.

Lower Delaware River (Delaware Direct Watershed)

The 300-mile long Delaware River winds its way through four states on the eastern coast of the United States, encompassing 42 counties and 838 municipalities. The river serves a variety of important residential, commercial, and industrial functions, including fishing, transportation, power cooling, and recreational purposes. The river also serves as an important source of drinking water for PWD and other utilities in the regions through which it passes.

The Delaware Direct Watershed encompasses the lower 20 miles of the Delaware River, before it discharges to the ocean. The watershed is located entirely within the City. About 70% of total land area in the watershed falls within PWD's CSO boundaries, which includes the tidal portion of the Delaware River, or about 15.6 stream miles.

The population of the Delaware Direct Watershed is approximately 500,000 and close to 99% of residents live within the CSO area. Like all the CSO watersheds, this area is highly urbanized, however, it does not support the level of industrial activity as seen within the Schuylkill River CSO area. Residential and commercial uses account for about 63% of total land uses in the watershed, while industrial uses account for close to 9%.

2.2 CSO Control Options

For each watershed, PWD has developed a suite of CSO control options based on four primary approaches, including:

- Low-Impact Development
- Tunneling
- Transmission, Plant Expansion and Treatment
- Transmission and Satellite Treatment.

LID (green infrastructure approaches)

For each watershed, PWD has developed a range of LID CSO control options (e.g., 25, 50, 75, and 100% of runoff from impervious surfaces managed through green infrastructure),

representing different levels of implementation. The LID approach focuses on restoring a more natural balance between stormwater runoff and infiltration, reducing pollutant loads, and controlling runoff rates at levels that minimize stream bank erosion. A variety of controls are incorporated into the different LID options, including disconnection of impervious cover, bioretention, subsurface storage and infiltration, green roofs, swales, and tree canopy. Land-based measures are a key part of this approach because they provide benefits to the community beyond water quality improvement (e.g., recreational opportunities, improved aesthetics, and increased home values).

The LID options also include a variety of water-based approaches to CSO control, including bed and bank stabilization and reconstruction, aquatic habitat creation, plunge pool removal, improvement of fish passage, and floodplain reconnection. The ultimate goal of this component of the LID program is to restore designated uses and ultimately remove CSO streams from the state's list of impaired waters. Similar to the land-based approaches described above, stream restoration will provide a number of benefits beyond water quality improvement.

Traditional Infrastructure-based Management Measures

The Tunneling, Transmission, Plant Expansion and Treatment, and Transmission and Satellite Treatment options for CSO control include traditional storage, conveyance, and treatment measures within the collection and treatment system. For each watershed, PWD has developed a number of variations based on these three infrastructure-based approaches. For example, in each watershed, a range of different Tunneling options is currently being evaluated, along with a range of options for both Satellite Treatment and Plant Expansion.

The traditional infrastructure-based measures have two main drawbacks. First, as noted above, the LID-oriented measures provide several important environmental, social, and public health benefits to the community beyond water quality improvement. Traditional infrastructure-based measures typically do not provide these benefits.

Second, traditional infrastructure-based measures may not address the root causes of impairment in Philadelphia's urban streams, where the primary causes of impairment are modified flow patterns and habitat degradation. Infrastructure-based measures are typically focused on removing loads of specific pollutants rather than restoring natural flow conditions and habitat. As such, they may assist in meeting some specific water quality parameters (e.g., reducing the number of overflow events), but do not necessarily support or enhance/restore the living resources (i.e., the aquatic and riparian ecosystems) of the watersheds.

To obtain maximum benefits and CSO control, PWD is currently considering many of the traditional infrastructure options (particularly the Plant Expansion options), in combination with LID measures. Traditional infrastructure options are expected to play an important role in

developing cost-effective and feasible solutions. For more detailed information on the suite of CSO management options currently being considered by PWD, see LTCPU.

References

U.S. Census Bureau. 2000. 2000 Census of Population Social and Economic Characteristics, Philadelphia, Bucks, Chester, Delaware and Montgomery Counties, Pennsylvania.

3. General Methodology and Data

3.1 Overview of the TBL Approach

The TBL approach reflects the fact that society and its enterprises – including the institutions that work specifically in the public interest (e.g., water and wastewater utilities) – typically are engaged in activities intended to provide the greatest total value to the communities they serve. These values extend well beyond the traditional financial bottom line that portrays only cash flows (i.e., revenues and expenditures) of a standard financial analysis. PWD and similar utilities that serve the public interest also need to consider their stewardship and other responsibilities, and to thus account for how they may generate values that contribute towards the "social" and "environmental" bottom lines. Hence, a more complete and meaningful accounting of PWD activities needs to provide a TBL perspective that reflects all three bottom lines: financial, social, and environmental.

In many ways, this TBL perspective is very similar to how an economist would define a comprehensive benefit-cost analysis that attempts to account for the full range of internal and external costs and benefits of an activity (project, or program), including nonmarket outcomes. The TBL approach provides an organizing framework within which the broad array of benefits and costs can be portrayed and communicated. This TBL approach should include both those outcomes that can be quantified and reasonably well monetized in dollar terms, as well as outcomes that are less amenable to reliable valuation and instead require qualitative discussion.

Accordingly, this TBL assessment of the benefits and external costs of the various relevant CSO control options for Philadelphia relies to a large extent on the tools and methods deployed by natural resource economists to estimate market and nonmarket values for a broad array of relevant environmental and social impacts. The sections below, and the more technically-oriented appendices, provide additional detail for the broad range of impacts that are assessed in this TBL evaluation of the PWD's CSO control options.

3.2 Key Inputs to the TBL Analysis

As noted above, the TBL analysis evaluates CSO control options that have been defined by PWD and CDM. Accordingly, most of the key physical inputs to our analyses (e.g., number and general location of trees planted, the number of stream miles impacted, the types of vehicles used on various construction and maintenance activities, power requirements associated with construction, the timing of various project activities) were provided by CDM.

3.3 General Overview of Methods and Key Assumptions

Key assumptions and basic methodological approaches used for the overall TBL analysis are detailed below. Assumptions and methods associated with each specific benefit and external cost category are discussed in the subsequent section.

External costs and benefits. As part of our analysis, we evaluate the "external" or ancillary costs and benefits associated with each of the CSO options (i.e., costs that are not included in traditional engineering estimates of the expense to build and operate facilities). External costs include, for example, time spent and fuel lost in construction-related traffic delays, and air quality impacts associated with construction and implementation activities (including the carbon footprint of concrete requirements under the traditional infrastructure alternatives). Under the LID alternatives, many of the air quality and energy impacts result in ancillary benefits in the form of carbon sequestration, air pollutant removal, and energy savings due to the cooling effect and other impacts provided by adding trees and other vegetation.

General methods for quantifying and/or valuing outcomes. The benefit and external cost estimates are derived from standard approaches as developed and used by environmental impact and valuation professionals and organizations. Many of the key methods, models and data are developed and deployed routinely by the U.S. Environmental Protection Agency (EPA) and other relevant federal agencies. For example, the air quality impacts of added trees is based on a model developed and applied by the U.S. Forest Service for Philadelphia. The resulting estimates of projected changes in ambient air quality (i.e., ozone and particulate matter concentrations) is then analyzed using EPA's Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates reductions in health risks and associated monetary values for the given change in ambient air quality. Similar reliance on well established federal and other models, methods, and data underlie most of the key benefit estimates derived in this study.

Time path for realizing benefits. Results presented below represent the discounted sum of annual values over the 40-year planning horizon (2010–2049). For each benefit and cost category, we applied a time path over which the different benefits and costs accrue. Our timelines are based on implementation, construction, and maintenance schedules provided by CDM, as well as on a tree growth model that applies to benefits dependent on the number of additional trees to be planted in the watershed. For example, the benefits associated with air pollutant removal from trees will not be fully realized in the first year of project implementation. Our analysis takes into account the percentage of trees planted each year as well as the rate at which the trees grow and mature (assumed here to be 20-years after they are planted).

Present value estimates. Our monetary results are in present value terms [2009 U.S. dollars (USD)] and are based on an inflation rate of 4% and a nominal discount rate of 4.875% applied over the 40-year planning horizon. Later in this report, we present the results of sensitivity analyses that were conducted to evaluate the impact of using alternative escalation and discount rates.

Additivity versus double-counting. The benefits presented below are additive, meaning they can be added together to generate a total value. However, the results of the property value analysis are likely to include some overlap and double-counting of benefits measured under several of the other benefit categories. For example, the anticipated energy savings enjoyed at tree-shaded properties are likely to be capitalized into the property values for those residences (depending on the extent to which current and prospective owners take anticipated energy costs into account when valuing properties). Likewise, enhanced greenspace-related recreational opportunities in the neighborhood are also likely to be capitalized (at least in part) in property values. At the same time, the property value analysis does reflect some unique values that are not embodied in the other estimated categories (e.g., aesthetics). Thus, the interpretation of the property value estimates needs to be carefully considered. For the purposes of this analysis, we include 50% of the estimated property value benefits to avoid this potential double-counting.

Omissions, biases, and uncertainties. Analyses of social and environmental benefits invariably require the use of assumptions and approaches (e.g., benefits transfer) that interject uncertainty about the accuracy or comprehensiveness of the empirical results. Throughout our analysis, and as detailed in the appendices, we have attempted to be explicit and reasonable about what assumptions and approaches we are adopting. We also provide summaries in each appendix of the key omissions, biases, and uncertainties (OBUs) that we believe are embedded in our work, and describe how the results of the analysis would likely have been impacted (e.g., whether benefits would have increased, decreased, or changed in an uncertain direction) if the omission or data limitation had been avoidable.

Sensitivity analyses. In conjunction with the OBU issues, we conducted several sensitivity analyses to explore how changing some of the key assumptions would impact our findings. The results of these sensitivity analyses are summarized in Chapter 6 (and are also described in relevant appendices).

4. The Benefits and External Costs of PWD's CSO Control Options

The TBL analysis of benefits and external costs is organized according to a series of benefit categories. The general approach and results for each category are described below. Considerable additional detail can be found in the associated appendices. It is important to note that not all options generate every type of benefit described below. Likewise, some options create external costs (negative benefits, such as added energy consumption and carbon emissions) within some of the categories.

4.1 Recreational Use and Values (creekside and non-creekside)

The green infrastructure, or LID-based, options include stream restoration and riparian buffer improvements, which will result in an anticipated increase in creekside (i.e., near stream) recreational opportunities in green areas along and adjacent to the impacted waters. Most of this added activity is anticipated for land-based, near water activities such as jogging, biking, walking, picnicking, and so forth. Little or no increases are expected in in-stream recreation (direct water contact or angling is not anticipated or encouraged in some relevant watershed areas).

Under the LID options, recreational opportunities will also improve in non-creekside areas, due to the general increase in vegetated and treed acreage in the relevant portions of the City. These non-creekside recreational benefits also are included in the analysis.

The more traditional infrastructure approaches (e.g., tunnels) are not expected to generate any appreciable changes in these types of recreational levels or values. While these approaches are aimed at reducing CSO overflow events – which will yield some water quality improvement – these options do not result in improved streamside or urban landscape conditions. Thus, there are no projected recreational benefits estimated for these options.

Total recreational benefits associated with improvements made under the LID options are a function of the additional recreational trips ("user days") taken as a result of these improvements, and the benefit (or direct use value) derived from each trip. To estimate additional recreational use and associated direct use benefits, we relied on a recent report prepared for the Philadelphia Parks Alliance by the Trust for Public Lands. The 2008 report, *How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?* (Parks Report), provides visitation data and direct use values for a variety of recreational uses and activities at

Philadelphia's parks. We tailored these data to individual watersheds based on conversations with park staff, detailed watershed and park management plans, and on-site visits

Based on these methods and data, we estimate an increase of nearly 350 million outings over the 40-year period (i.e., 2010–2049) for the 50% LID option. Over 70% of these outings are for near-stream activities, and the balance are non-creekside. The monetized present value of these added activities over the 40-year period amounts to over $520 million (these and all other dollar values described in this report are in 2009 USD, unless otherwise noted). Additional detail is provided in Appendix A.

4.2 Enhanced Aesthetics (reflected in residential property values)

Trees and plants improve urban aesthetics and community livability, and several empirical studies show that property values are higher when trees and other vegetation are present in urban neighborhoods. Applying a benefits transfer approach to interpret the relevant body of LID-related published hedonic valuation literature, coupled with neighborhood-specific baseline property values, we derive an estimated aggregate increase in property values for each LID option and impacted city area. The literature used includes a Philadelphia-specific study published by Wachter and Wong (2006).

For the 50% LID option applied city-wide to all four watershed areas, the estimated value of enhanced residential property values amounts to over $1.1 billion. We reduce this by 50% to avoid potential double-counting with several of the other benefit categories, since our objective here is to capture aesthetics-related benefits only. The resulting $575 million in present value benefits only accounts for residential properties; enhanced values for nonresidential properties are not included in this analysis. Additional detail is provided in Appendix B.

4.3 Heat Stress-Related Premature Fatalities Avoided

The City has endured several excessive heat events (EHEs), with numerous documented cases of premature fatality attributed to heat stress in some summer periods (e.g., over 100 premature fatalities attributed to heat stress in the EHEs of 1993). The episodes have been studied extensively by the City, the federal Centers for Disease Control (CDC), and EPA.

Green infrastructure (trees, green roofs, and bio-retention areas) – such as would be implemented under the LID-oriented options – creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air and reduce the urban heat island (UHI) effect. This cooling effect will be sufficient to actually reduce heat stress-related fatalities in the City during extreme heat wave events.

Applying the standard methods developed and applied for relevant federal agencies, our analysis (supported by Dr. Larry Kalkstein and his associates) links increases in vegetated areas to potential reductions in summer temperatures and, ultimately, to projected cases of heat stress fatalities avoided. City-wide, we estimate 196 premature fatalities avoided over the 40-year project planning horizon, for the 50% LID option.

Standard EPA methods and values (i.e., value of statistical life, VSL, estimates) were then used to monetize these reductions in premature fatalities. For the 50% LID option, the present value of the reduced risk of premature fatality from heat stress amounts to nearly $1.1 billion. This estimate does not include the avoided medical costs and reduced suffering of morbidity impacts (i.e., the costs associated with those individuals who would otherwise suffer adversity from heat stress, but would not be projected to die from the impact). As such, the omission of morbidity events means that our premature mortality-oriented estimates are probably a lower-bound of the total public health benefit attributable to the LID options. Additional detail is provided in Appendix C.

4.4 Water Quality and Aquatic Habitat Enhancements and Values

A core objective of any CSO control option is to improve water quality and aquatic ecosystems in the impacted watersheds. The traditional infrastructure options (e.g., plant expansions, tunnels) are aimed at reducing the number of overflow episodes, but do little to directly improve the physical riparian area environment (i.e., riparian and aquatic ecosystems and habitat areas) or otherwise enhance living resources in many of the City's watershed environments. In contrast, the LID options, in conjunction with the related watershed restoration efforts, are expected to generate improvements to these natural resources.

To estimate the value of these improvements, a benefits transfer approach was applied, drawing on a meta analysis of nonuse value estimates associated with different potential baseline levels and improvements in water quality. A primary objective of this meta-analysis was to develop a tool (regression model), based on existing (primary) studies, that could be used to predict what individual households would be willing to pay for improvements in water quality to a specified level. Using the regression tool, we were able to apply information related to the Philadelphia CSO control options (e.g., demographic data and expected water quality/habitat improvements under each option) to estimate total willingness to pay (WTP) for water quality improvements.

Due to differences in demographics and location (distance from the resource), we separately evaluated WTP for households within Philadelphia and nearby households outside of the City. The households outside of Philadelphia included in this analysis fall within the greater Philadelphia Metropolitan Area (MA; including Bucks, Chester, Delaware and Montgomery counties).

The results for the 50% LID option indicate an estimated annual WTP of approximately $10 to $15 per household per year, when the water quality and related habitat enhancements are fully realized. Over the 40-year analysis period, this amounts to an estimated city-wide value of over $330 million. Additional detail is provided in Appendix D.

4.5 Wetland Enhancement and Creation

Under the LID options, watershed restoration and related efforts are expected to create or enhance over 190 acres of wetlands in the relevant watersheds. We monetized these added and enhanced wetland acres according to the range of services they are expected to provide in the urban area watersheds, using a benefits transfer approach based on the relevant published literature of wetland values.

For the 50% LID option, these added wetland acres and related services are estimated to provide over $1.6 million in added value city-wide, in present value terms, over the 40-year project planning period. Additional detail is provided in Appendix E.

4.6 Poverty Reduction Benefits of Local Green Infrastructure Jobs

Jobs associated with large civil works projects, such as CSO control options, are not typically counted within an economically sound benefit-cost analysis. This is because the labor retained in such projects typically would be gainfully employed in other ventures (private or public investments), meaning that there typically is a *transfer* of employment across potential activities rather than a real net gain in jobs. Therefore, in this analysis of PWD's CSO control options, we are not counting jobs under any of the options as new employment creation benefits.

However, there are some relevant considerations to be taken into account for some of the CSO control options. Specifically, there are likely to be social benefits (e.g., avoided social costs) when jobs can be steered to local citizens who are typically unemployed (or under-employed) due to a lack of education and training and other social circumstances.

Specialized labor is required for construction of conventional stormwater management solutions (e.g., boring, tunneling). Such skilled laborers might typically be already employed in the construction field. In contrast, green infrastructure projects, as embodied in the LID options, creates the opportunity to hire unskilled – and otherwise unemployed – laborers for landscaping and restoration activities. Thus the benefits of providing these green jobs include the avoided costs of social services that the City would provide on behalf of the same people if they remained unemployed. These "green infrastructure jobs" therefore have the unique capability to provide not just employment, but a crucial stepping stone to help people escape from poverty. The

benefits of providing "green infrastructure jobs" include the avoided costs of social services that the City would provide on behalf of the same unskilled people if they remained unemployed, outside the workforce, and trapped in poverty.

For the 50% LID option, we project over 15,000 job years will be created for low-skilled local workers, over the 40-year period, across the four watershed areas. Based on the avoided costs of social services linked to these added job years, we estimate a present value benefit of nearly $125 million. For addition detail, see Appendix F.

4.7 Energy Use and Related Changes in Carbon and Other Emissions

Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. In addition, diverting stormwater from wastewater collection, conveyance and treatment systems reduces the amount of energy needed to pump and treat the water, which in turn reduces emissions of greenhouse gases (GHG, including carbon dioxide, CO_2) and other air pollutants (e.g., sulfur dioxide, SO_2, and nitrogen oxides, NO_x) from power plants. Reduced energy demands in buildings, and increased carbon sequestration by added vegetation, also result in a lower carbon footprint (reduced CO_2 emissions).

Our analysis calculates the amount of energy consumption added (or reduced) by the various CSO control options, and calculates the value of the added energy costs (or the energy cost savings), at current energy prices. The energy use levels include, for example, the home energy cost savings provided by the shading offered by trees added under the LID options. Also included is the increased consumption of motor fuel associated with construction-related vehicle traffic delays imposed by any of the options. Some CSO control options generate net energy savings (i.e., the LID options), and others result in a net increase in energy use and costs (e.g., the tunnel options). It is important to note that our analysis includes only those energy costs that are external to engineering cost estimates. The cost of fuel used by construction and maintenance vehicles, and electricity costs associated with excavation and other construction activities are reflected in the cost estimates developed by CDM.

In addition to the direct expense of added energy consumed (or savings from use of less energy), we also assess the level of CO_2 emissions added (or reduced or sequestered) by each option. Thus, for example, the LID options reduce CO_2 emissions at power plants by providing energy savings at shaded homes, plus the added trees sequester some CO_2 as well. These reductions more than offset the added emissions associated with implementation-related activities, such as added vehicle fuel use during the installation of green infrastructure. The net savings in emissions are valued using a "social cost of carbon" estimate derived from the Intergovernmental

Panel on Climate Change (IPCC) of the climate change damages contributed by each metric ton (MT) of CO_2 equivalent (CO_2e) emitted. The value used is \$12/MT.

In contrast, traditional infrastructure options tend to increase net CO_2 emissions, because they require extensive excavation activity and concrete, and also required added energy use in pumping and treating the collected and stored stormwaters. Again, the direct cost of the energy used in constructing and operating the traditional infrastructure approaches are not included in our cost estimates, because they are internal costs that are reflected in the capital and operation and maintenance (O&M) costs developed for each of those CSO control options (i.e., the energy cost is included in the engineering cost estimates provided by CDM). However, in our work, we do include the external costs associated with the added energy use required by these options.

Finally, the changes in energy use also change the amount of SO_2 and NO_x emitted from power plants. These changes in emissions are estimated based on region-specific data from EPA, and assigned monetary values based on EPA methods that reflect the average health benefit (or cost) associated with each ton of emission reduced (or added).

For the 50% LID option, our analysis indicates a net energy savings over the 40-year planning period of nearly 370 million kilowatt hours (kWh) of electricity and nearly 600 million British thermal units (Btus) of natural gas. The 50% LID option will result in close to 0.5 million gallons of "wasted" motor fuel consumed by vehicles delayed by construction activities. Emissions reductions over that period include over 1,500 MT of SO_2, 1.1 million MT of CO_2, and a small reduction in NO_x emissions of 38 MT.

The monetized present value of these changes from the 50% LID option amount to nearly \$34 million for energy savings, over \$21 million for reduced CO_2 emissions, and over \$46 million for reduced net damages from SO_2 and NO_x emissions. For additional detail, see Appendix G.

4.8 Air Quality Pollutant Removal from Added Vegetation

Trees and vegetation improve air quality by filtering some airborne pollutants (particulate matter and ozone). Likewise, reduced energy consumption results in decreased emissions (SO_2 and NO_x) from power generation facilities (as described and evaluated in the previous section). These air quality improvements can reduce the incidence and severity of respiratory illness.

To evaluate the air quality impacts of added trees, we used a model developed by the U.S. Forest Service, for application in Philadelphia. We analyzed the resulting estimates of projected changes in ambient air quality (i.e., ozone and particulate matter concentrations) using software developed by the EPA to calculate the avoided health effects from the contribution of trees to

reducing ozone and $PM_{2.5}$ concentrations, and to estimate the economic value of the avoided health effects. EPA's BenMAP (Ver. 3.0.15), was used to conduct this analysis.

The avoidable air pollution-related health effects estimated in this analysis are:

- Premature mortality (from ozone and $PM_{2.5}$)
- Onset of irreversible chronic bronchitis ($PM_{2.5}$)
- Heart attacks (non-fatal acute myocardial infarctions) ($PM_{2.5}$)
- Hospital admissions (non-fatal) for respiratory and cardiovascular conditions (from ozone and $PM_{2.5}$)
- Emergency room visits for asthma (from ozone and $PM_{2.5}$)
- Respiratory symptoms (days of illness) (from ozone and $PM_{2.5}$)
- Work loss days ($PM_{2.5}$) and school absence (ozone).

The quantified estimates are then monetized using standard EPA dollar values for each applicable adverse health endpoint.

For the 50% LID option, applied across the four watershed areas, we estimate that after full implementation and tree maturation, the health effects avoided will include between 1 and 2.4 premature fatalities avoided per year, 1.2 heart attacks avoided per year, and over 700 cases of other respiratory illness days avoided per year. The present value of the associated monetized benefits is over $130 million over the 40-year period. Additional detail is provided in Appendix H.

4.9 Construction- and Maintenance-Related Disruption Impacts

All of the CSO options will result in some level of disruption due to construction and program activities. Social costs of disruption can include traffic delays, limited access to places of business, increased noise and pollution, and other inconveniences. Under all of the CSO alternatives, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia. Travel time delays can be caused by:

- General traffic slowdowns associated with an increase in the number of trucks and construction equipment on the road
- Slowdowns from trucks entering and exiting construction or landscaping sites
- Lane or road closures associated with construction in the roadway or road right-of-way.

In addition to the value of "lost" time spent in traffic, construction-related delays can result in increased costs associated with additional fuel used by vehicles as a result of slower speeds and occasional vehicle stops and idling.

Using standard methods and data for estimating traffic delays and associated fuel use and time loss, we estimated the 40-year present value of these external costs for each CSO control option. City-wide, the present value of these external costs for the 50% LID option is $5.6 million, and for the 30' Tunnel option, it is more than 200 times larger, at over $13.4 billion. Additional detail is provided in Appendix I.

References

Wachter, S.M. and G. Wong. 2006. What is a tree worth? Green-city strategies and housing prices. *Real Estate Economics* 36(2):2008.

5. Summary of Results

The following sections summarize the benefits and external costs of the CSO control options currently being considered by PWD. We first present the results of our analysis on a City-wide basis, highlighting the benefits and costs across the CSO watersheds. More detailed tables, providing benefits and costs in each watershed by category, are provided at the end of this chapter.

Again, it is important to note that throughout the following sections, we refer to the green infrastructure CSO control options as LID-based approaches. We categorize the different options based on different levels of implementation (e.g., the 50% LID option would manage runoff from 50% of impervious surfaces in Philadelphia through green infrastructure). Green infrastructure and LID are used interchangeably throughout the next chapter and appendices.

We also refer to the traditional infrastructure options according to different levels of implementation. For example, throughout the report we draw upon the “30’ Tunnel” option as an example alternative. This option includes a system of storage tunnels serving all watersheds with an effective diameter of 30 ft. Alternative tunneling options (e.g., 15’, 20’, 25’, and 35’ options), are also being evaluated by PWD and the impacts of all alternatives are examined here.

5.1 Benefits of LID CSO Control Options

Figure 5.1 presents the total net benefits (defined here as benefits minus the external costs of construction disruption) for the LID CSO control options over the 40-year project evaluation period. City-wide, total present value benefits range from about $1,935 million (2009 USD) under the 25% LID option to more than $4,466 million under the 100% LID option.

The relative make up of total benefits by watershed is consistent across LID options. As shown in Figure 5.1, the Tacony-Frankford Creek Watershed accounts for about 20 to 22% of total benefits under each option. Cobbs Creek makes up about 8 to 11%, while the Schuylkill and Delaware River Watersheds account for about 25 to 27% and 42 to 44% of total net benefits, respectively.

Figure 5.2 shows the breakdown of total City-wide benefits by benefit category for the 50% LID option. As shown, reduced heat-stress fatalities, increased property values, and increased recreational opportunities make up the majority of total benefits. These categories account for 37, 20, and 18% of total benefits, respectively.

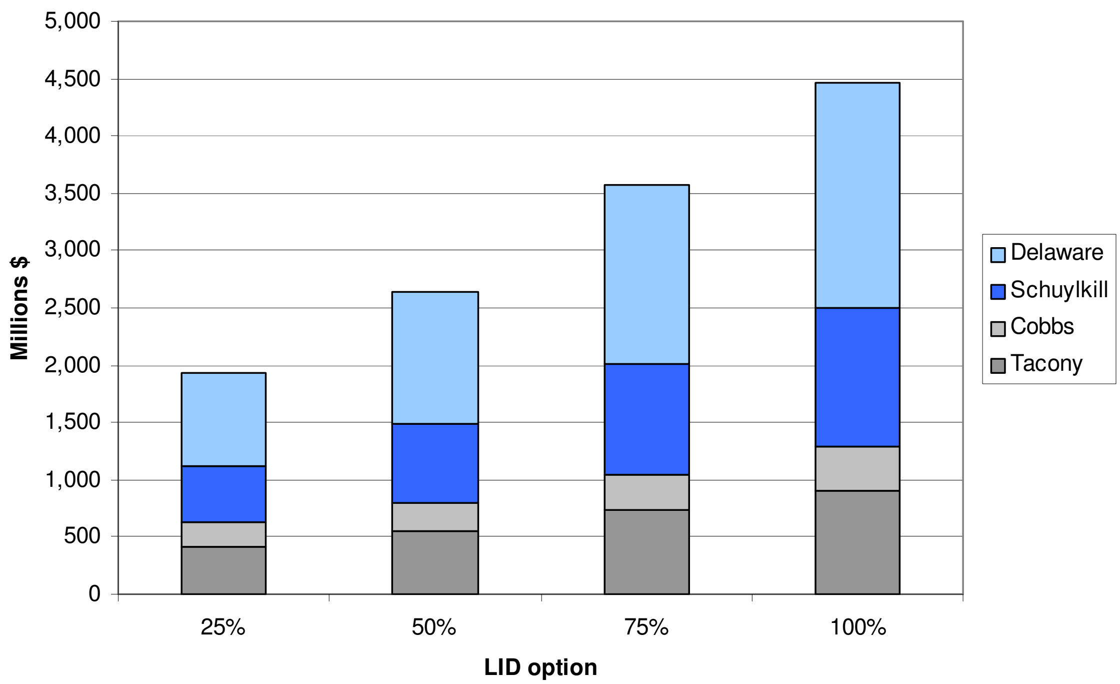

Figure 5.1. City-wide net benefits for LID options by watershed.

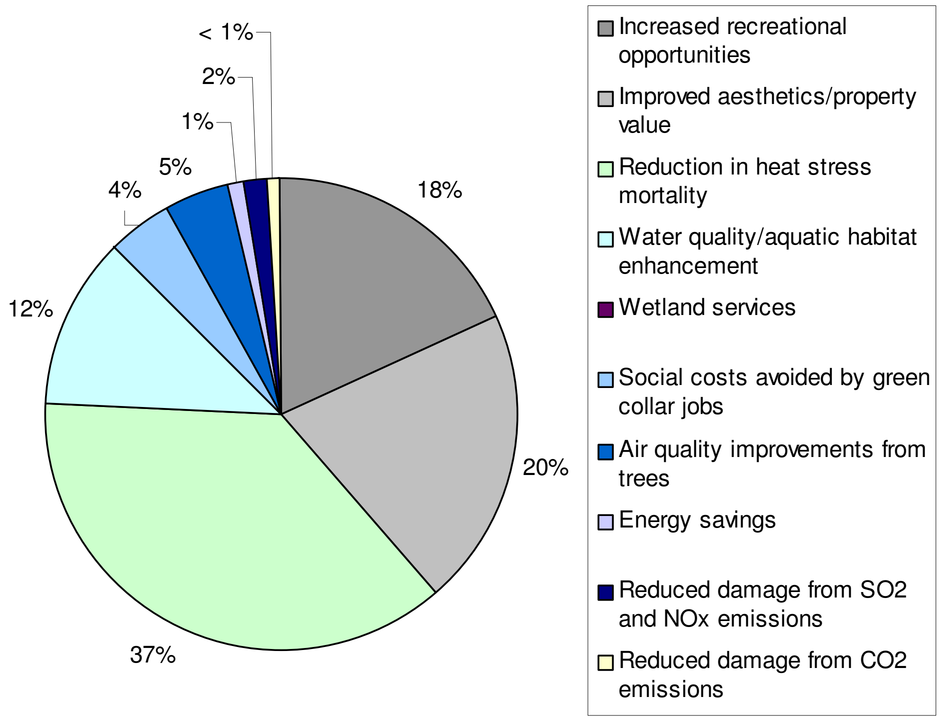

Figure 5.2. Shares of City-wide present value benefits of key CSO options: Cumulative through 2049.

The benefits associated with improved water quality and aquatic habitat also account for a substantial portion of total benefits (12%), while net energy savings, reduced NO_x and SO_2 emissions, and carbon sequestration all account for less than 2%. "Green jobs" and air quality improvements due to pollutant removal from trees, both account for about 5% of total benefits. The percent breakdown of benefit categories shown in Figure 5.2 is consistent across the LID options.

5.2 Benefits and External Costs of Example CSO Options

To show a more direct comparison of benefits and external costs of the different CSO control options, Figure 5.3 provides City-wide estimates for the LID and tunneling CSO Control options. These options were chosen to demonstrate the difference in net benefits between green and traditional infrastructure. The reporting of these results is not intended to indicate that a final PWD decision will be based on these two alternatives.

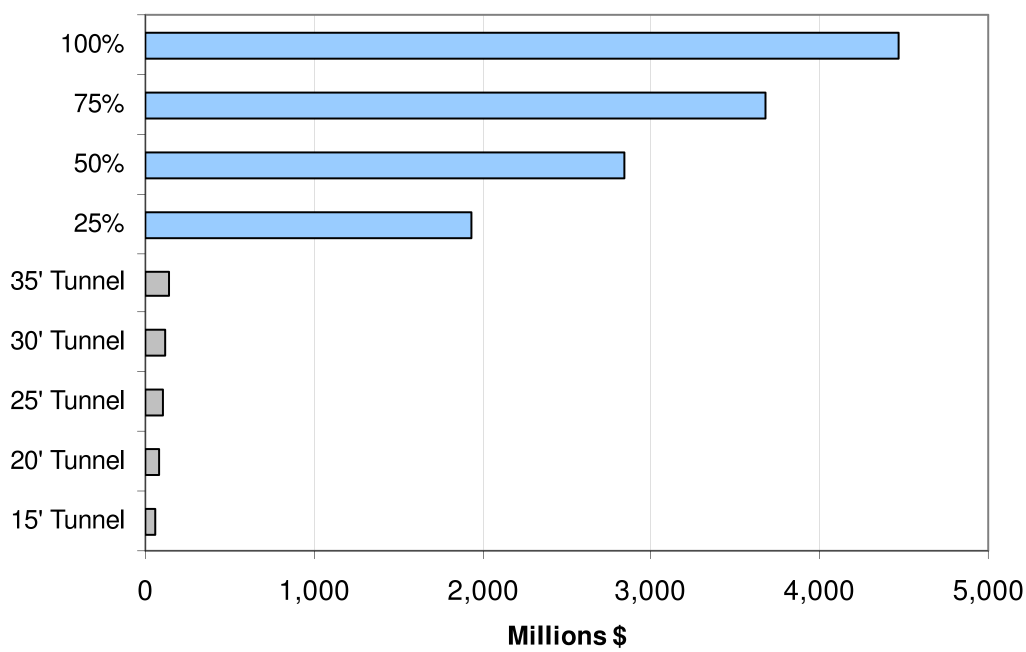

Figure 5.3. City-wide present value benefits/external costs of the LID and tunneling CSO control options, over 40-year project period (2009 USD).

As shown in Figure 5.3, on a City-wide basis, the net external costs of the tunneling options ranges from about $61.6 million under the 15’ Tunneling option, to more than $140 million under the 35’ Tunneling option. This compares to the range of net present value benefits for the LID options of $1,935 million to $4,466 million, as reported in Section 5.1 above.

Table 5.1 shows City-wide estimates for total net benefits (benefits minus external costs) of the 50% LID and 30’ Tunnel options over the 40-year project period. This comparison is intended to provide a bit more detail into the break down of the individual options. The ratio of the external costs of the tunneling options to the net benefits of the LID options varies considerably by watershed. Section 5.3 provides a comparison of the costs and benefits of these different options for each watershed.

As discussed earlier in this report, the physical unit measures associated with the monetary values presented above are an important component of our discussion of total benefits. For the LID options, for example, physical unit measures include the number of lives saved as a result of reduced heat stress, the number of new recreational visitor days, and the energy and carbon savings associated with increased vegetated area, among others.

Table 5.2 presents City-wide estimates for the physical unit measures associated with the 50% LID and 30’ Tunneling options. The measures shown below can be directly tied to the monetary values provided in Table 5.1.

5.3 Detailed Results by Watershed

The following tables provide detailed results for the CSO control options being evaluated in each of the CSO watersheds. Tables 5.3–5.6 show the present value estimates (2009 USD) for each benefit/external cost category, while Tables 5.7–5.10 provide the physical unit measures associated with these values. Finally, for comparison purposes, Figures 5.4–5.7 provide a visual depiction of the present value net benefits/external costs for the tunneling versus LID options within each watershed. The tables and figures included in the following pages include options in the Delaware River Watershed.

Table 5.1. City-wide present value benefits of key CSO options: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$524.5	
Improved aesthetics/property value (50%)	$574.7	
Reduction in heat stress mortality	$1,057.6	
Water quality/aquatic habitat enhancement	$336.4	$189.0
Wetland services	$1.6	
Social costs avoided by green collar jobs	$124.9	
Air quality improvements from trees	$131.0	
Energy savings/usage	$33.7	$(2.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$46.3	$(45.2)
Reduced (increased) damage from CO_2 emissions	$21.2	$(5.9)
Disruption costs from construction and maintenance	$(5.6)[b]	$(13.4)
Total	**$2,846.4**	**$122.0**

a. 28' Tunnel option in Delaware River Watershed.
b. Parentheses indicate negative values.

Table 5.2. City-wide natural unit benefits of key CSO options: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	247,524,281	
Additional non-creekside recreational user days	101,738,547	
Reduction in number of heat-related fatalities	196	
Annual WTP per household for water quality and aquatic habitat improvements[b]	$9.70–$15.54	$5.63–$8.59
Wetlands created or restored (acres)	193	
Green collar jobs (job years)	15,266	
Change in particulate matter ($PM_{2.5}$) due to increased trees ($\mu g/m^3$)	0.01569	
Change in seasonal ozone due to increased trees (ppb)	0.04248	
Electricity savings due to cooling effect of trees (kWh)	369,739,725	
Natural gas savings due to cooling effect of trees (kBtu)	599,199,846	
Fuel used (vehicles for construction and O&M) (gallons)	493,387	1,132,409
SO_2 emissions (metric tons)	(1,530)	1,452
NO_x emissions (metric tons)	(38)	6,356,083
CO_2 emissions (metric tons)	(1,091,433)	347,970
Vehicle delay from construction and maintenance (hours of delay)	346,883	796,597

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.3. Present value benefits of key CSO options in Tacony-Frankford Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$161.2	
Improved aesthetics/property value (50%)	$85.0	
Reduction in heat stress mortality	$249.9	
Water quality/aquatic habitat enhancement	$23.7	$13.3
Wetland services	$0.3	
Social costs avoided by green collar jobs	$27.0	
Air quality improvements from trees	$28.3	
Energy savings/usage	$7.3	$(0.4)
Reduced (increased) damage from SO_2 and NO_x emissions	$10.0	$(8.8)
Reduced (increased) damage from CO_2 emissions	$4.6	$(1.1)
Disruption costs from construction and maintenance	$(1.2)	$(2.2)
Total	**$596.0**	**$0.8**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.4. Present value benefits of key CSO options in Cobbs Creek Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$100.2	
Improved aesthetics/property value (50%)	$24.8	
Reduction in heat stress mortality	$89.8	
Water quality/aquatic habitat enhancement	$30.6	$17.2
Wetland services	$0.3	
Social costs avoided by green collar jobs	$8.6	
Air quality improvements from trees	$9.0	
Energy savings/usage	$2.3	$(0.5)
Reduced (increased) damage from SO_2 and NO_x emissions	$3.2	$(6.5)
Reduced (increased) damage from CO_2 emissions	$1.5	$(1.0)
Disruption costs from construction and maintenance	$(0.4)	$(2.8)
Total	**$270.0**	**$6.5**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.5. Present value benefits of key CSO options in Schuylkill River Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$90.1	
Improved aesthetics/property value (50%)	$193.7	
Reduction in heat stress mortality	$297.1	
Water quality/aquatic habitat enhancement	$86.2	$48.5
Wetland services	$0.3	
Social costs avoided by green collar jobs	$28.9	
Air quality improvements from trees	$30.4	
Energy savings/usage	$7.8	$(0.6)
Reduced (increased) damage from SO_2 and NO_x emissions	$10.7	$(14.2)
Reduced (increased) damage from CO_2 emissions	$4.9	$(1.7)
Disruption costs from construction and maintenance	$(1.3)	$(3.4)
Total	**$748.9**	**$28.5**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.6. Present value benefits of key CSO options in Delaware River Watershed: Cumulative through 2049 (2009 million USD)

Benefit categories	50% LID option	30' Tunnel option[a]
Increased recreational opportunities	$173.0	
Improved aesthetics/property value (50%)	$271.2	
Reduction in heat stress mortality	$420.9	
Water quality/aquatic habitat enhancement	$195.8	$110.0
Wetland services	$0.7	
Social costs avoided by green collar jobs	$60.4	
Air quality improvements from trees	$63.4	
Energy savings/usage	$16.3	$(0.9)
Reduced (increased) damage from SO_2 and NO_x emissions	$22.4	$(15.7)
Reduced (increased) damage from CO_2 emissions	$10.3	$(2.1)
Disruption costs from construction and maintenance	$(2.7)	$(5.1)
Total	**$1,231.6**	**$86.2**

a. 28' Tunnel option in Delaware River Watershed.

Table 5.7. Natural unit benefits of key CSO options in Tacony-Frankford Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	80,527,887	
Additional non-creekside recreational user days	22,714,215	
Reduction in number of heat-related fatalities	46	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	35	
Green collar jobs	3,303	
Electricity savings due to cooling effect of trees	79,771,661	
Natural gas savings due to cooling effect of trees	129,277,877	
Fuel used (vehicles for construction and O&M)	106,449	184,336
SO_2 emissions (metric tons)	(330)	283
NO_x emissions (metric tons)	(8)	1,082,609
CO_2 emissions (metric tons)	(235,478)	63,986
Disruption delay from construction and maintenance	74,840	129,672

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.8. Natural unit benefits of key CSO options in Cobbs Creek Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	50,478,407	
Additional non-creekside recreational user days	8,629,946	
Reduction in number of heat-related fatalities	17	
WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	39.93	
Green collar jobs	1,050	
Electricity savings due to cooling effect of trees	25,475,530	
Natural gas savings due to cooling effect of trees	41,285,620	
Fuel used (vehicles for construction and O&M)	33,995	235,991
SO_2 emissions (metric tons)	(105)	208
NO_x emissions (metric tons)	(3)	1,256,965
CO_2 emissions (metric tons)	(75,201)	59,809
Disruption delay from construction and maintenance	23,901	166,009

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.9. Natural unit benefits of key CSO options in Schuylkill River Watershed: Cumulative through 2049

Benefit categories	50% LID option	30' Tunnel option[a]
Additional creekside recreational user days	40,371,870	
Additional non-creekside recreational user days	22,991,914	
Reduction in number of heat-related fatalities	55	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	30	
Green collar jobs	3,535	
Electricity savings due to cooling effect of trees	85,676,380	
Natural gas savings due to cooling effect of trees	138,847,060	
Fuel used (vehicles for construction and O&M)	114,328	285,414
SO_2 emissions (metric tons)	(355)	456
NO_x emissions (metric tons)	(9)	1,653,470
CO_2 emissions (metric tons)	(252,908)	98,814
Disruption delay from construction and maintenance	80,380	200,775

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

Table 5.10. Natural unit benefits of key CSO options in Delaware River Watershed: Cumulative through 2049

Benefit categories	50% LID option	28' Tunnel option[a]
Additional creekside recreational user days	76,146,118	
Additional non-creekside recreational user days	47,402,472	
Reduction in number of heat-related fatalities	78	
Annual WTP per household for water quality and aquatic habitat improvements[b]	\$9.70–\$15.54	\$5.63–\$8.59
Wetlands created or restored (acres)	88	
Green collar jobs	7,379	
Electricity savings due to cooling effect of trees	178,816,154	
Natural gas savings due to cooling effect of trees	289,789,289	
Fuel used (vehicles for construction and O&M)	238,615	426,667
SO_2 emissions (metric tons)	(740)	505
NO_x emissions (metric tons)	(18)	2,363,038
CO_2 emissions (metric tons)	(527,847)	125,361
Disruption delay from construction and maintenance	167,762	300,141

a. 28' Tunnel option in Delaware River Watershed.
b. WTP per household in Philadelphia, MA, including Bucks, Chester, Delaware, Montgomery, and Philadelphia counties.

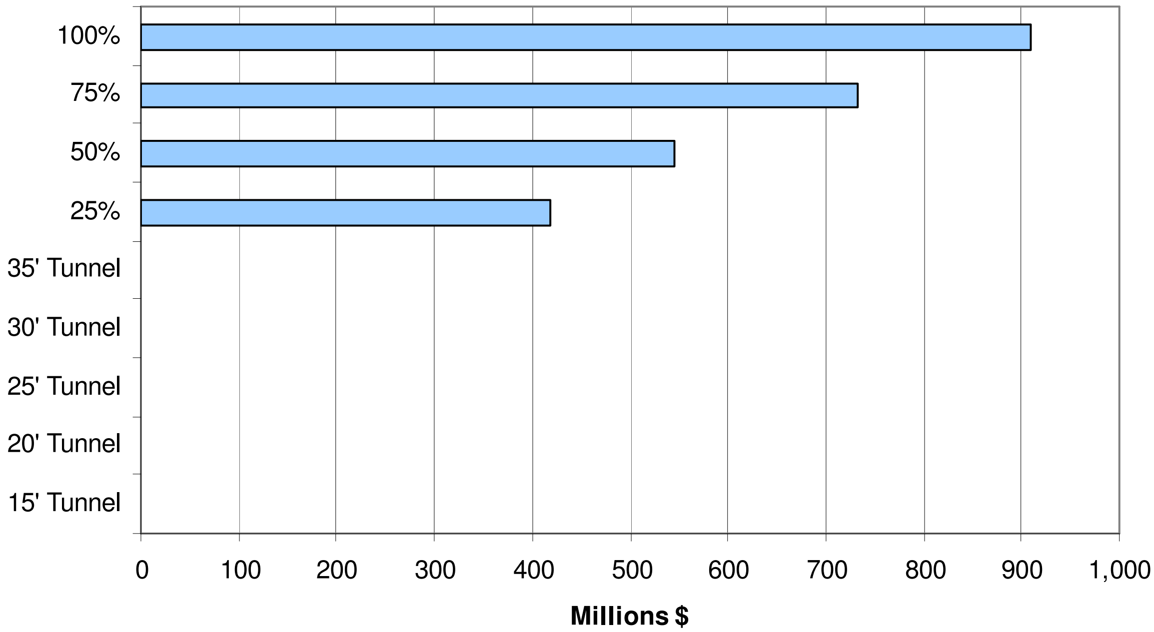

Figure 5.4. Benefits less external costs for key CSO options in the Tacony-Frankford Creek Watershed.

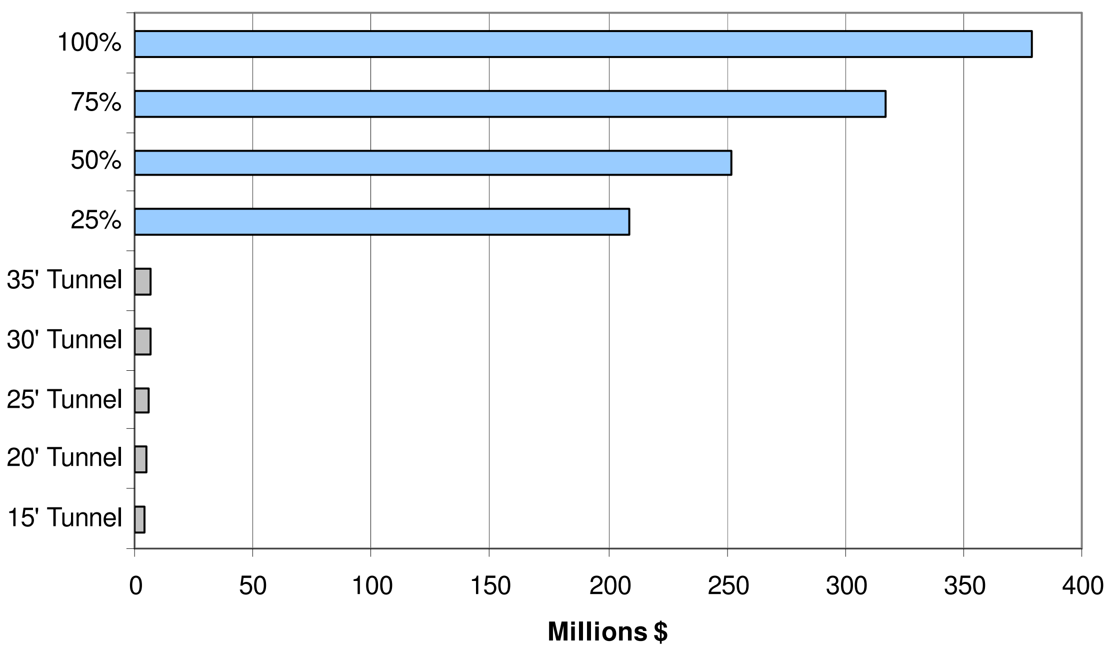

Figure 5.5. Benefits less external costs for key CSO options in the Cobbs Creek Watershed.

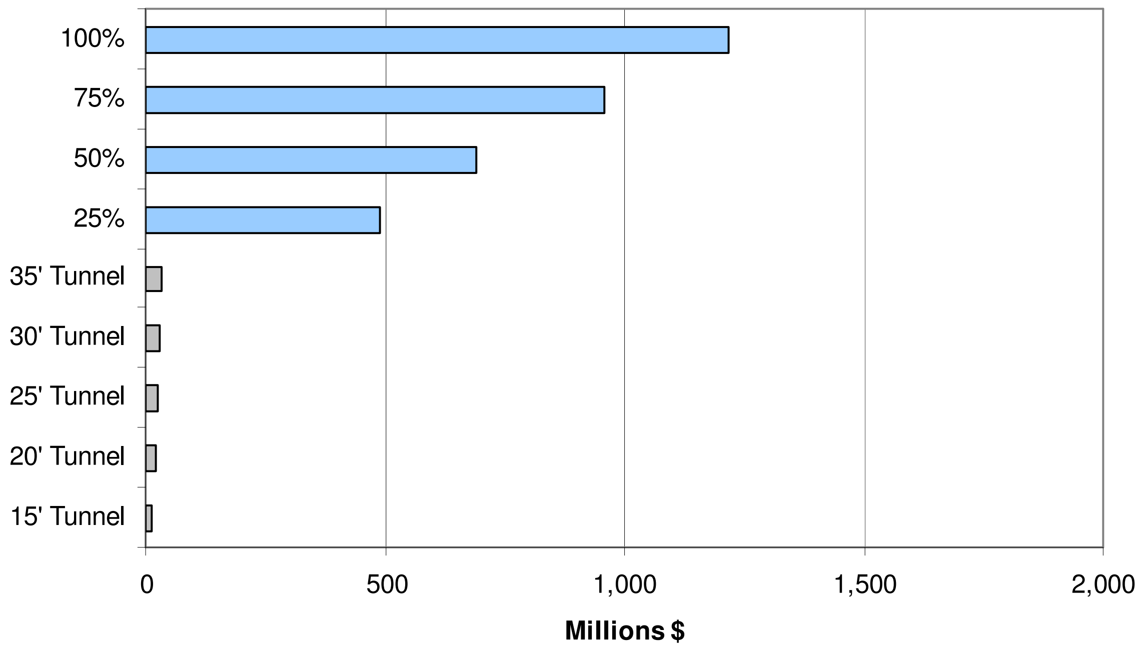

Figure 5.6. Benefits less external costs for key CSO options in the Schuylkill River Watershed.

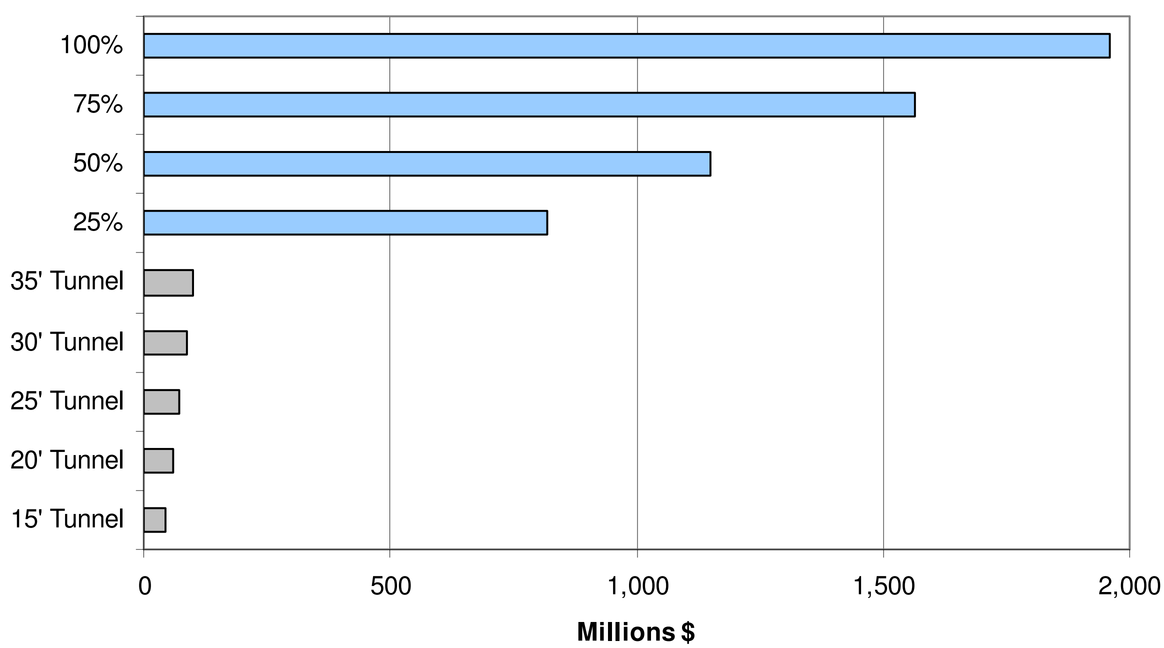

Figure 5.7. Benefits less external costs for key CSO options in the Delaware River Watershed.

6. Key Uncertainties and Sensitivity Analyses

As detailed in the appendices of this report, there are a number of uncertainties (e.g., discount rate, social cost of carbon) and potential sources of variability (e.g., changes in energy costs) surrounding our analysis. To explore the impacts of these uncertainties on our overall results, we implemented a series of sensitivity analyses. The results of these analyses are discussed below.

Sensitivity analysis involves systematically changing the value of a key input or variable to see how it affects the outcome of the analysis. The change in results shows how sensitive the project outcome is to changes in individual factors. Sensitivity analysis is often performed by varying a particular input by equal amounts greater to and less than the current value (e.g., +/- 50%). The ultimate purpose of sensitivity analysis is to understand which assumptions are important to the choice of a particular policy or project option, and what those assumptions would have to be to change the decision on which option to pursue.

As part of the sensitivity analysis, we have explored the effect of a number of key assumptions on our overall results, including:

- ***Discount rate***. It is common practice to perform a sensitivity analysis on the discount rate used to determine the present value of costs and benefits. We therefore evaluated the benefits and external costs of the CSO options under alternative discount rate scenarios. Under the first scenario, we raised the nominal discount rate to 6.5%, (up from 4.875% in the current analysis) to reflect a 2.5% real discount rate, given the cost escalator (i.e., general inflation rate) of 4%. As a second scenario, we lowered the real discount rate to 0% (because of intergenerational equity aspects associated with the LID options). This entails lowering the nominal discount rate to 4% (i.e., setting discount rate to same value as the price escalator). Table 6.1 shows the results of this analysis for the 50% LID and 30' Tunnel options.

  As shown in Table 6.1, under the 50% LID option, net benefits decrease by 27% city-wide when the discount rate is increased to 6.5% (i.e., future benefits are "discounted" at a higher rate). Under the 4% discount rate scenario, benefits increase by about 21% city-wide from the baseline analysis (where the discount rate is equal to 4.875%).

  Under the 30' Tunneling option, relative impacts are larger and more varied across watersheds. For example, in the Tacony-Frankford Watershed, increasing the discount rate to 6.5% results in a 66% decrease in net benefits. In dollar terms, this represents a decrease of about $550,000. The large percentage decrease is due to the relatively low net benefits associated with this option in the Tacony-Frankford Watershed. City-wide, net benefits decrease by 34% and increase by 27% under the 6.5% and 4% discount rate scenarios, respectively.

Table 6.1. Sensitivity analysis: Discount rates

	Present value net benefits (millions, 2009 USD)			% change from baseline estimate*	
Discount rate	**4.875%**	**6.5%**	**4.0%**	**6.5%**	**4.0%**
50% LID option					
Tacony	$596.0	$416.2	$737.0	-30%	24%
Cobbs	$270.0	$185.6	$335.7	-31%	24%
Schuylkill	$748.9	$551.9	$903.8	-26%	21%
Delaware	$1,231.6	$895.1	$1,495.4	-27%	21%
City-wide	$2,846.4	$2,048.7	$3,471.9	-27%	21%
30' Tunnel option					
Tacony	$0.8	$0.3	$1.3	-66%	59%
Cobbs	$6.5	$3.7	$8.7	-42%	34%
Schuylkill	$28.5	$18.9	$36.0	-34%	26%
Delaware	$86.2	$57.2	$108.6	-34%	26%
City-wide	$122.0	$80.1	$154.6	-34%	27%

- ***Social cost of carbon***. There is currently quite a debate among experts and in the literature regarding the true social cost of carbon. For our analysis, we assume a cost of $12 per ton (MT), as reported by the IPCC. To evaluate how an increase in the social cost of carbon would impact our results for the different CSO control options, we conducted a sensitivity analysis comparing benefits and external costs with a higher social cost of carbon of $48 versus the IPCC's average of $12. The $48 per ton is about half of the high-level estimates reported by the IPCC (which include values of $85 to $98 per MT). Table 6.2 shows the results of this analysis for the 50% LID and 30' Tunnel options. More detailed results are included in Appendix G of this report.

  As shown below, changing the social cost of carbon does not significantly impact the net benefits of the 50% LID option on a percentage basis. This is because the benefits associated with carbon sequestration and reduced emissions make up a very small component of the total net benefits (e.g., < 1% under the 50% LID option). In dollar terms, the change in net benefits under the 50% LID option amounts to more than $63 million.

Under the 30' Tunnel option, the impact of an increased social cost of carbon has a much larger relative effect on overall results. City-wide, net benefits decrease by about 15% with an increase in the social cost of carbon from $12/MT to $48 MT. In dollar terms, this change amounts to about $18 million.

Table 6.2. Sensitivity analysis: Social cost of carbon

Social cost of carbon	Present value net benefits (millions, 2009 USD)		% change from baseline estimate
	\$12/MT	**\$48/MT**	
50% LID option			
Tacony	\$596.0	\$609.7	2.30%
Cobbs	\$270.0	\$274.3	1.62%
Schuylkill	\$748.9	\$763.6	1.97%
Delaware	\$1,231.6	\$1,262.3	2.50%
City-wide	\$2,846.4	\$2,910.0	2.23%
30' Tunnel option			
Tacony	\$0.8	\$(2.5)	(400.25)%
Cobbs	\$6.5	\$3.5	(45.54)%
Schuylkill	\$28.5	\$23.4	(18.06)%
Delaware	\$86.2	\$79.9	(7.35)%
City-wide	\$122.0	\$104.3	(14.53)%

- ***Electricity prices***. Electricity and other fossil fuel-based energy prices are expected to increase if a federal climate policy is introduced. Energy prices can also increase in the future due to a number of other factors (as evident by the price volatility seen in recent years). For our analysis, we assume a conservative estimate of \$0.10 per kWh of electricity. This assumption affects the benefits associated with electricity savings under the LID CSO control options (electricity costs associated with power use within any CSO control option are not included in our analysis, because they are included in engineering cost estimates).

  To evaluate the impact of our assumption for the current rate of electricity, we conducted a sensitivity analysis that doubled this rate (e.g., up to \$0.20 per kWh). The analysis shows that the rate of electricity has a very small impact on net benefits of the LID options. In all cases, net benefits increased by close to 1% as a result of the additional savings that would occur with higher electricity rates.

- ***WTP for water quality improvements***. As reported in Appendix D, we conducted a sensitivity analysis to evaluate how WTP per household fluctuates in response to changes in baseline water quality and the level of water quality/habitat improvement (as defined by the WQ_{10}). The results of this sensitivity analysis (reported in Appendix D) indicate that within the reasonable range of assumptions related to these variables, WTP per household does not vary appreciably as these input values change, but seem to follow a reasonable progression. WTP is more sensitive to the actual improvement in water quality as opposed to the baseline index value used in the analysis.

A. Recreational Use and Values

The LID CSO control options currently being evaluated by PWD would provide (and enhance) recreational amenities within PWD's CSO watersheds. The LID options include a substantial increase in vegetated acreage (including "treed" acreage) throughout the City. Much of this "green" acreage would be in the form of trees planted along streets in residential areas or will be planted in areas that are currently vacant or abandoned. This "greening" of Philadelphia would increase enjoyment and participation in neighborhood activities such as walking, biking or jogging on sidewalks, bench sitting, and/or other general outdoor recreation.

In addition, under all of the LID options, PWD would implement a stream restoration program intended to improve aquatic habitat in affected water bodies. The program is focused on physical in-stream improvements (primarily within the main stem water body associated with each watershed), as well as on improvement and expansion of riparian areas. In some watersheds, this would include improving riparian lands located within Fairmount Park and/or other open space areas. Activities in these areas might include trail construction and restoration, removal of invasive species, and other activities that would improve access along streams and rivers within the combined sewer area. In other areas, access to water bodies would be improved through key land and trail connections, enhancing recreational use in these areas.

The following sections outline Stratus Consulting's methodology for estimating the benefits associated with the increased recreational opportunities that will be available under the LID options for CSO control. Estimates of total benefits within each watershed are also provided. As described below, this analysis addresses "direct use" benefits only. Nonuse values associated with increased recreational opportunities are addressed in a subsequent analysis (see Appendix D).

A.1 General Methodology

To estimate total benefits of increased recreational activity under the LID options, we separately evaluated the benefits derived from improvements made as part of the stream restoration program (which are planned for implementation under all of the LID options) and those associated with a general increase in vegetated acreage throughout the CSO watersheds. For the purposes of this analysis, we refer to these benefits as "creekside" and "non-creekside" benefits, respectively.

The following sections describe the general methodology used to evaluate creekside and non-creekside recreational benefits. Subsequent sections provide more detailed descriptions of how our analyses were tailored to each watershed.

A.1.1 Recreational use

As a first step to our analyses, we estimated the additional recreational use expected to occur under the different LID options in each watershed. To do this, we relied heavily on a recent report prepared for the Philadelphia Parks Alliance by the Trust for Public Lands. The 2008 report, *How Much Value Does the City of Philadelphia Receive from its Park and Recreation System?* (Parks Report), provides visitation data for a variety of recreational uses and activities at Philadelphia's parks.[1]

The Parks Report provides data for visitation to parks in Philadelphia in general, and does not report recreational use at individual parks. We therefore used a per-acre estimate (number of visits per acre of Philadelphia park land) to evaluate potential changes in recreational activity under the different LID options in each watershed. We tailored these per-acre estimates to individual watersheds based on conversations with park staff, detailed watershed and park management plans, and on-site visits. We also made assumptions related to per-acre recreational use in non-park areas (e.g., on residential streets). Assumptions related to per-acre use in each watershed are described in detail in subsequent sections.

Finally, the recreational use values reported in the Parks Report are for Philadelphia residents only. Our estimates therefore do not include recreational use (or benefits) for non-Philadelphia residents.

A.1.2 Direct use values

The total recreational benefits associated with improvements made under the LID options are a function of the additional recreational trips ("user days") taken as a result of these improvements, and the benefit (or direct use value) derived from each trip.

Because recreational activities are not traded in the market (i.e., there is no fee for participation), it can be difficult to establish the direct use values associated with them. However, economists have developed a number of techniques for valuing "non-market" goods and resources, such as recreation. For example, economists have often determined the value of a recreational experience based on the consumer's WTP for the recreational experience in the private marketplace.

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1. The number of park visits reported in the Parks Report were determined via a professionally conducted telephone survey of 600 Philadelphia residents. (The random-digit-dialed survey had an accuracy level of plus or minus 4%.) Residents were asked to answer for themselves; for those adults with children under the age of 18, a representative proportion were also asked to respond for one of their children.

For this analysis, we were able to rely on direct use values for specific recreational activities, as reported in the Parks Report. The model used to quantify these values is based on the "Unit Day Value" method as documented in Water Resources Council recreation valuation procedures by the U.S. Army Corps of Engineers. The Unit Day Value model counts park visits by specific activity, and assigns each activity a dollar value, based on WTP for park activities. For example, playing in a playground is worth $3.50 each time to each user. Running, walking, or rollerblading on a park trail is worth $4.00. For a more detailed description of how direct use values were calculated, see the Parks Report.

A.2 Non-creekside Recreation

To estimate benefits associated with a general increase in vegetated acreage (including treed acreage), we relied on inputs from CDM regarding the planned increase in vegetated acreage under the LID options for each watershed. We modified the number of vegetated acres provided by CDM to reflect only those acres that would result in additional or enhanced recreational activity. For example, we subtracted out the estimated number of acres expected to be planted in green roofs (also an input provided by CDM).

In addition to accounting for green roofs, we also subtracted the number of vegetated acres estimated for implementation in parking lots. To do this, we assumed that the vegetated acreage would be distributed based on the current pattern of impervious surface area in each watershed. For example, in the Tacony-Frankford Watershed, approximately 17% of impervious area (not including roofs) can be attributed to parking lots. We therefore assumed that 17% of the vegetated acreage planned under each alternative would be planted in parking lots. Thus, after accounting for green roofs, 17% of the remaining vegetated acreage planned for the Tacony-Frankford Watershed would not result in recreational benefits.

For the Schuylkill River Watershed, we also subtracted the number of acres identified in the Schuylkill River Master Plan (EDAW, 2003) as being available for recreational development (150 acres). This area was evaluated as part of the creekside recreational analysis. We assumed a similar area, on a per-stream mile basis, would be available for recreational development along the Delaware River and accounted for this in our analysis.

Table A.1 shows the planned increase in vegetated acreage assumed to result in recreational benefits for the LID CSO options in each watershed.

Table A.1. Planned increase in vegetated acreage assumed to result in recreational benefits under the LID options

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	231	87	126	236
50% LID	822	312	832	1,715
75% LID	1,169	445	1,247	2,584
100% LID	1,404	534	1,528	3,171

Our next step was to estimate the number of recreational visits, or "user days," per acre for specific recreational activities that would occur as a result of the increases in vegetated acreage. We used visitation data for specific activities (e.g., walking the dog, walking on sidewalks/trails, and picnicking or bench sitting) from the Parks Report as the basis for this estimate. We then assumed that on a per-acre basis, the vegetated acreage planted under the LID options would support about 10% of the recreational activity seen at an average park in Philadelphia.

Table A.2 presents the annual additional recreational activity (in terms of "user days") under the LID CSO options in each watershed, assuming full program implementation. Table A.3 shows total additional recreational user days over the 40-year project evaluation period. The estimates shown in Table A.3 take into account the LID implementation timeline provided by CDM.

Table A.2. Additional non-creekside recreational user days under LID CSO control options each year (at full program implementation)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	310,000	117,300	169,200	317,300
50% LID	1,104,100	419,500	1,117,600	2,304,100
75% LID	1,571,300	597,500	1,676,300	3,472,900
100% LID	1,886,700	717,000	2,053,400	4,261,400

Table A.3. Additional non-creekside recreational user days under LID CSO control options over 40-year project period

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	6,376,780	2,413,061	3,481,727	6,528,626
50% LID	22,714,215	8,629,946	22,991,914	47,402,472
75% LID	32,326,746	12,292,929	34,486,588	71,448,114
100% LID	38,815,401	14,751,738	42,245,022	87,670,535

A.2.1 Direct use value of additional recreational visits

To estimate the monetary value of additional recreational activity, we applied direct use values from the Parks Report for the recreational activities described above. We used 50% of the direct-use values reported in the Parks Report to account for differences in the value of recreational activities in parks versus non-park areas (i.e., walking on a sidewalk).

To estimate total benefits over the 40-year project life, we scaled annual benefits based on the LID implementation timelines provided by CDM. Table A.4 shows the present value benefits associated with non-creekside recreational activity expected to occur under the LID CSO options in each watershed.

Table A.4. Direct-use benefits associated with non-creekside recreational visits under LID CSO control options (present value estimates for 40-year project period)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	$4,499,952	$1,702,843	$2,456,977	$4,684,956
50% LID	$16,028,916	$6,089,960	$16,224,881	$34,016,111
75% LID	$22,812,265	$8,674,846	$24,336,416	$51,271,313
100% LID	$27,391,164	$10,409,972	$29,811,370	$62,912,556

A.3 Creekside Recreation

The following sections describe Stratus Consulting's approach for estimating recreational benefits associated with the stream restoration component of the LID CSO options. For this evaluation, we adapted our methodology to account for differences in current and expected changes in recreational use in each watershed. Further, the stream restoration program is assumed to be implemented under all of the LID alternatives, therefore total benefits are the same at each level of LID (25–100%).

Our methodology and assumptions are based on an extensive review of watershed and park management/master plans (documented at the end of this appendix), on-site visits with PWD staff, and discussions with Fairmount Park representatives.

A.3.1 Tacony-Frankford Watershed

Tacony Creek Park, a unit of the Fairmount Park System, accounts for the majority of creekside recreational lands in the Tacony-Frankford Watershed. The park consists of 302 acres of land (including Juniata Park Golf Course) that form a narrow corridor of park along Tacony Creek

from the Montgomery/Philadelphia County border through Juniata Park. The park offers 2.5 miles of creekside trails and is reportedly used by residents for picnicking, running, walking, and fishing. Although an illegal activity, people do swim in the Tacony Creek Park section of the creek. Unsanctioned uses of the park include all terrain vehicle (ATV) use, dumping, graffiti, and drug activity.

Below Juniata Park Golf Course, the Tacony joins with now buried tributaries to form Frankford Creek. In order to deal with flooding and large influxes of stormwater, Frankford Creek has been completely channelized in concrete. The concrete channel prevents interaction between Frankford Creek and the groundwater system and eliminates streambed habitat needed to support aquatic life. The area surrounding Frankford Creek is highly industrialized and much of the creek is inaccessible.

Stream restoration activities in the Tacony-Frankford Watershed are focused on in-stream restoration and riparian area improvements along the 2.6 miles of stream through Tacony Creek Park and the 3.5 miles of Frankford Creek (south of Juniata Park through to the Frankford's confluence with the Delaware River). Major improvements related to recreational use include trail construction and restoration, expanded riparian areas, and improved access to the Tacony-Frankford main stem. Implementation of the Frankford Creek Greenway (as described in the Frankford Greenway Master Plan) is expected to include 3.1+ miles of trail and a number of recreational amenities.

Baseline recreational use

We first established a baseline estimate for current recreational activity in Tacony Creek Park. We limited the baseline to activity within the park because it is currently the only area in the Philadelphia County portion of the watershed that provides direct access to the main stem creek.

Our baseline estimate of recreational activity relies on survey data from the Tacony-Frankford River Conservation Plan (RCP), and qualitative descriptions from Fairmount Park Staff and the Tacony Creek Park Natural Lands Restoration Master Plan. We also used the Parks Report to help determine the mix of recreational activities occurring in the park.

The RCP survey reports stream-related recreational activity for the entire watershed (including tributaries). We therefore used geographic information systems (GIS) land use data to estimate the percentage of creek-related recreational activity that occurs along the Tacony main stem in Tacony Creek Park. We estimate that Tacony Creek Park currently supports about 70% of total creek-related recreation in the watershed. The remaining 30% is assumed to occur in tributaries and other areas of the watershed not relevant to our analysis.

Table A.5 shows the inputs and data sources used to establish a baseline estimate for recreational use along the creek. As shown below, the majority of residents in the Tacony-Frankford Watershed report that they rarely, if ever, spend recreational time along the creek. Conversations with park staff also indicate that this park gets very little use.

Table A.5. Assumptions and inputs used to establish baseline recreational use along Tacony-Frankford Creek

		Data source
General inputs		
2007 watershed population (Philadelphia County portion)	285,405	EPA BenMap 2007; Tacony-Frankford Integrated Watershed Management Plan (IWMP)
Percent of population less than 18 years old	26%	2000 Census
Recreational activities along the creek		
Percent of watershed residents under the age of 18 that recreate along the creek	12%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Percent of watershed residents over the age of 18 that recreate along the creek	39%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Average number of visits per year (both groups)	3	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Mix of recreational activities		
Walk along creek	53%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP
Other non-contact activities	38%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP; Parks Report
Fishing	8%	Tacony-Frankford RCP survey data as reported in the Tacony-Frankford IWMP

Based on the assumptions and inputs shown above, we estimate that Tacony-Frankford Creek supports approximately 192,320 recreational visits to the creek each year. This amounts to about $406,000 in annual direct-use benefits.

Additional recreational visits under LID options

To estimate total creekside recreational benefits in the Tacony-Frankford Watershed, we separately evaluate recreational use under the LID CSO control options in the following locations:

- Tacony Creek Park
- Juniata Creek Golf Course
- The planned Frankford Creek Greenway.

Tacony Creek Park. As a first step to our analysis of recreational activity in Tacony Creek Park, we calculated the average number of per-acre visits to all Philadelphia parks for specific activities expected to occur in Tacony Creek Park. These activities include:

- Visits to playgrounds and tot lots
- Picnicking or bench-sitting
- Walking on trails
- Walking dog in park
- Birdwatching/nature
- Bicycling on trails
- Running on park trails
- Fishing.

We then assumed that under the LID/stream restoration improvements, Tacony Creek Park would likely support about 40% of the per-acre visitation experienced at an average park in Philadelphia. To estimate total visitation to the park, we therefore applied 40% of the average number of recreational visits per acre of park land in Philadelphia to the 174 acres of Tacony Park (excluding Juniata Park Golf Course). Our 40% assumption is based on the relative "local" nature of the park (e.g., compared to the regional appeal of East and West Fairmount parks), surrounding neighborhood demographics, and discussions with Fairmount Park representatives.

Based on these assumptions, we estimate that approximately 2.1 million people would visit Tacony Park each year under the LID options (at full program implementation). This includes the baseline estimate of individuals who already visit the park, as well as visits from individuals who would have visited a park elsewhere in Philadelphia if the improvements along Tacony Creek had not taken place. These factors are accounted for in our estimate of total benefits, as described below.

Juniata Park Golf Course. We based our estimate of additional visits to Juniata Park Golf Course on data reported in the *Juniata Park Golf Course Land Use and Feasibility Study* (EDAW, 2008). This report indicates that odors associated with CSO events in Tacony Creek are one of many limiting factors for increasing visitation to the course.

EDAW reports that there are currently about 11,350 rounds of golf played at Juniata Park each year (2007 estimate). This compares to an average of 28,375 rounds reported for other public courses in Philadelphia, or 40% of average use. We assume that under the LID options, use might increase to about 50% of the average use at other courses, or to 14,190 rounds of golf (an additional 2,800 rounds).

Based on an average of 3 golfers per round, we estimate that as a result of the CSO improvements, approximately 8,500 individuals will golf at Juniata Park Golf Course that otherwise would not have. This includes individuals who would have golfed elsewhere in the City (and are therefore not included in the overall benefit estimates reported below).

We use a conservative estimate for increase in use of the course as a result of CSO improvements because the park is plagued by non-CSO related problems such as graffiti and vandalism. In addition, Juniata Park is smaller than many other public courses and does not have the same historic or regional appeal as some of the other more well-used courses (e.g., Cobbs Creek Golf Course).

Frankford Creek Greenway. The planned Frankford Creek Greenway is a massive public works project that would include 3.1+ miles of trail construction along Frankford Creek and would restore much of Frankford Creek to its natural stream bottom. To estimate the number of visits to the new greenway, we relied on the same methodology described above for our analysis of increased use at Tacony Creek Park.

We first estimated the total area (acres) of the greenway, based on 3.5 stream miles and an assumed greenway width from the stream zone. Based on our assumptions, we estimate that the greenway would be approximately 190 acres. We then estimated per-acre visitation for activities expected to occur along the greenway.

With the exception of fishing and playgrounds/tot lots, the activities within the greenway were assumed to be the same as those included in the Tacony Creek Park analysis. We did not include fishing as a specific recreational activity because the concrete walls on the side of the stream channel are assumed to prevent direct contact with the stream. Additionally, it is unclear whether playgrounds and tot lots would be included as part of the greenway (they were not described in the Frankford Greenway Master Plan). As with the Tacony Creek Park analysis, we assumed that the Frankford Greenway would support about 40% of the recreational use of an average park in Philadelphia, on a per-acre basis.

Based on these inputs, we estimate that more than 1.9 million individuals will visit the greenway each year, once it is fully constructed.

Total additional recreational visits. We assume that under the LID options, approximately 70% of the recreational visits reported above would be "new" visits, meaning they would not have occurred if the LID stream restoration program had not been implemented. This assumption implies that the remaining 30% of recreational visits would have occurred at parks or golf courses elsewhere in the City if the LID improvements had not taken place. Although there is a marginal benefit associated with these visits (otherwise individuals would continue to visit the other parks), these benefits are not included in our analysis.

Table A.6 provides a summary of total additional recreational visits in the Tacony-Frankford Watershed under the LID options. The number of additional visits is reported on an annual basis (assuming full program implementation) as well as in terms of total visits over the 40-year project period. Total visits over the project period were determined based on the stream restoration implementation timeline provided by CDM.

Table A.6. Summary of total additional recreational visits in the Tacony-Frankford Watershed under LID options

Additional visits to Tacony Creek Park under LID options (minus baseline)	1,934,000
Visits to Frankford Greenway	1,910,000
Additional (person) visits to Juniata Park Golf Course	8,500
Percent of visits that are new recreational visits	70%
Additional annual recreational user days s	2,696,800
Additional recreational user days over 40-year project period	80,527,887

Direct use value of additional recreational visits

To estimate the monetary value of additional creekside recreational visits under the LID CSO control options, we applied direct-use values from the Parks Report, weighted by specific recreational activity. Based on these values, we estimate that the increased recreational activity will result in approximately $6.1 million each year (2009 USD), at full program implementation. This amounts to more than $145 million in direct use benefits over the 40-year project period, in present value terms (2009 USD). Present value estimates were determined based on the stream restoration implementation timeline provided by CDM.

A.3.2 Cobbs Creek Watershed

Cobbs Creek Park, located on the western edge of Philadelphia, accounts for the majority of recreational/park land in the Cobbs Creek Watershed. The Park's 220 acres encompass nearly 13 miles of stream that eventually drain to the Delaware River. The main stem, which is 8.2 miles, accounts for the majority of total stream length. The remaining stream length is made up of tributaries such as Indian Creek, and smaller, un-named streams.

For the purposes of this analysis, we focus solely on recreational use along the Cobbs Creek mainstem, as this will be the focus of PWD's stream restoration program. All improvements along the creek are expected occur within Cobbs Creek Park, which borders the creek throughout most of the CSO area. No additional recreational amenities are planned (i.e., nothing similar to the Frankford Creek Greenway). Stream restoration program activities are expected to result in

improved water quality, restored and expanded trails, and improved access to the creek via expanded riparian areas.

To estimate recreational use along Cobbs Creek, we employed a methodology similar to the methodology used for our analysis of the Tacony-Frankford Watershed. Our methodology and results are described below.

Baseline recreational use

In the absence of data for current recreational use at Cobbs Creek Park, we relied on the per-acre baseline use established for Tacony Creek Park. We applied this baseline estimate to the 220 acres of Cobbs Creek Park, assuming that per-acre use is about 15% higher at Cobbs Creek Park than at Tacony Creek Park. This assumption was based on on-site visits and qualitative descriptions of each park. Based on our per-acre use application (with the 15% adjustment), we estimate that currently, Cobbs Creek Park supports about 280,000 visits each year.

Additional recreational visits to Cobbs Creek under the LID options

Similar to our analysis of recreational benefits in Tacony Creek Park, we calculated the average number of per-acre visits to all Philadelphia parks for specific activities expected to occur in the park under the LID options. We assumed the same mix of recreational activities for Cobbs Creek as we did for Tacony Creek Park.

We applied the per-acre estimates for specific recreational activities to Cobbs Creek Park and assumed that under the LID/stream restoration improvements, Cobbs Creek Park would likely support about 40% of the per-acre visitation experienced at an average park in Philadelphia. This assumption is based on the relative "local" nature of the park (e.g., compared to the regional appeal of East and West Fairmount parks), surrounding neighborhood demographics, and discussions with Fairmount Park representatives.

Based on these assumptions, we estimate that approximately 2.7 million people would visit Cobbs Creek Park each year under the LID options (at full program implementation). This includes the baseline estimate of individuals who already visit the park, as well as visits from individuals who would have visited a park elsewhere in Philadelphia if the improvements along Cobbs Creek had not taken place.

To estimate the number of additional visits under the LID options, we subtract out the baseline visits and assume that about 70% of the total visits are *new* visits (rather than visits that would otherwise have taken place at other city parks). Based on these assumptions, we estimate that improvements under the LID options will result in approximately 1.7 million additional visits each year, at full program implementation. This amounts to an additional 50.5 million visits over the 40-year project period, based on the implementation timeline provided by CDM.

Direct use value of additional recreational visits

To estimate the monetary value associated with these increased visits, we applied direct-use values from the Parks Report, weighted by specific recreational activity. We estimate that improvements under the LID options will result in approximately $3.9 million recreation-related benefits each year, at full program implementation. This amounts to $94 million in present value benefits (2009 USD) over the 40-year project period.

A.3.3 Schuylkill River Watershed

Our analysis of recreational benefits in the Schuylkill River Watershed relies on the information and data reported in the Tidal Schuylkill River Master Plan (EDAW, 2003). The study area of the Master Plan includes the eight-mile stretch of the tidal Schuylkill River (and adjacent land) from the Fairmount dam to the Delaware River. This area consists of a significant amount of industrial land uses that are adjacent to residential, open space, institutional, and other public uses such as the Philadelphia International Airport.

There are numerous active and inactive rail lines in the area, including the large and active East Side Yard for CSXT. Several major road corridors also run adjacent to and through the study area including I-95, I-76 (Schuylkill Expressway), I-676, Route 291/Passyunk Avenue, Grays Ferry Avenue, University Avenue, South Street, Walnut Street, Chestnut Street, and Market Street.

Land use data reveal that over half of the Master Plan study area (54.75%) is currently devoted to manufacturing, utilities, parking, and transportation (rail and street rights-of-way). Another 29% of land is categorized as wooded, vacant, or water (water associated with industrial uses, not the river and canals). Only 2.52% is currently categorized as recreation and 2.81% as residential of all types.

The Master Plan proposes a number of major public investments in the revitalization of the tidal Schuylkill River. These investments include greenway and trail improvements, including neighborhood linkages to the river and "streetscapes," as well as infrastructure improvements. Based on the Master Plan's full implementation, the potential development program for the study area could include the development of:

- Over 3,270 residential units
- Over 1,600,000 square feet of retail uses
- Over 11,300 square feet of restaurants
- Over 1,000,000 square feet of office space
- Over 2,000,000 square feet of flex/industrial space
- Over 100,000 square feet of cultural facilities

- Over 150 acres of new green space and park land
- Over 8 miles of new multi-purpose trails
- Marinas and boat storage for about 400 boats.

Improvements made as part of the LID CSO control options in the Lower Schuylkill River will play a role in the implementation of the Tidal Schuylkill River Master Plan. For our analysis of recreational benefits, we focus on the development opportunities described above that can be directly tied to LID CSO control implementation. Based on our understanding of the LID options, this includes the implementation of 150 "creekside" acres of new open space and park land, including trails and streetscape improvements, and the opportunities for new marinas and boat storage. The benefits associated with these improvements are described in the following sections.

Additional recreational visits associated with new green space

To evaluate recreational benefits, we first estimate per-acre visitation for specific recreational activities associated with the additional open space and park land, based on the Parks Report. We then assume that recreational areas in the Lower Schuylkill River would support about 60% of the use of an average Philadelphia Park. This is higher than the 40% estimate used for the Tacony and Cobbs Creek parks due to the park's more regional nature. However, due to the abundance of recreational opportunities just upstream of the CSO area (e.g., East and West Fairmount parks, Boathouse Row) and the heavy industrial nature of the area, this area will likely see less use than many other parks in the region.

Additionally, we also assume that only about 50% of recreational visits to the Lower Schuylkill open space areas will be "new" visits (i.e., visits would not have taken place at another park in the region). This is also based on the abundance of recreational opportunities located just upstream of the Schuylkill CSO area.

Based on these assumptions, we estimate that the improvements identified in the Schuylkill River Master Plan (associated with green space, trails, and pedestrian linkages only) will amount to about 1.3 million new recreational visits per year, assuming full program implementation. This amounts to about 40.2 million new visits over the 40-year project period, taking into account the stream restoration implementation timeline provided by CDM. Our analysis assumes no baseline level of visitation to this area due to its highly industrial nature and current land uses.

Additional recreational visits for boating and fishing

In addition to the benefits associated with new green space, the Master Plan identifies opportunities for the development of marinas and boat storage for about 400 boats. We include this in our analysis of recreational benefits because it can be directly tied to improvements in

water quality as well as the implementation of aesthetic and recreational amenities (e.g., additional open space) under the LID CSO control options.

To estimate the number of new trips to the Lower Schuylkill River for fishing and boating, we rely on original survey data from the Parks Report, provided by the Trust for Public Lands.[2] We used these data to determine the number of average trips per year taken by Philadelphians who engage in fishing and/or boating. We then assume an average of 3 people per boat/fish trip and that about 60% of the trips taken on the Lower Schuylkill River would be "new trips" (i.e., would not have taken place elsewhere). Based on these assumptions, we estimate an additional 4,400 trips each year at full program implementation. This amounts to about 131,600 trips over the 40-year project period.

Direct use value of additional recreational visits

Similar to our analysis of Tacony and Cobbs Creek watersheds, we used direct-use values for specific recreational activities from the Parks Report to determine total benefits. Based on these values, we estimate the annual value of new recreational visits resulting from the implementation of 150 acres of open space, including trails and pedestrian linkages to the river, to be about $3.1 million (2009 USD) at full program implementation. Based on the implementation timeline provided by CDM, this amounts to more than $73.4 million in present value benefits (2009 USD) over the 40-year project period. Increased participation in boating and fishing in the Lower Schuylkill will provide an additional $19,172 in annual direct-use benefits, or a total of $460,000 in present value benefits over the 40-year project period.

A.3.4 Delaware River Watershed

In absence of specific data for the Delaware River Watershed, we assume that on a per-stream mile basis, the LID CSO control options for the Delaware River will include the same amount of open/green space area as planned for the Schuylkill River.

As noted above, there are about 150 acres (or about 21 acres per stream-mile) of open/green space planned for the Lower Schuylkill area, which encompasses about 8.7 miles of river. Applying this to the 15.6 miles of the Delaware River within PWD's CSO area, we estimate there will be about 341 acres of new open/green space under the LID CSO options. Similar to the Schuylkill Watershed, this additional acreage is separate from the vegetated acreage planned for areas throughout the watershed, as reported in the section on "non-creekside" recreational

2. The raw survey data is unweighted and does not account for differences in demographic characteristics of the study population and the population of Philadelphia County.

benefits. For our evaluation of non-creekside benefits, we subtracted out the open/green space acreage planned for the area along the river.

We used the same methodology as described for the Schuylkill River to estimate the recreational benefits associated with this new area. Based on this methodology, we estimate that implementation of the stream restoration program under the LID CSO control options will result in about 2.6 million additional creekside recreational visits each year, at full program implementation. This amounts to about 76.1 million visits over the 40-year project period, taking into account the project implementation timeline.

In terms of direct use benefits, additional recreational visits to the Delaware River will result in an annual benefit of $5.8 million (2009 USD), at full program implementation. Over the 40-year project period, this amounts to $139 million in present value benefits (2009 USD).

A.4 Summary of Results

Tables A.7 and A.8 provide a summary of total recreational benefits associated with the LID CSO control options. Table A.7 shows the additional number of recreational visits and the direct-use benefits, in present value terms, associated with additional non-creekside recreation. Table A.8 shows the same results for the creekside recreational analysis.

Table A.7. Summary of additional recreational visits under the LID CSO control options, over the 40-year project period

	Tacony	Cobbs	Schuylkill	Delaware
Non-creekside recreation				
25% LID	6,376,780	2,413,061	3,481,727	6,528,626
50% LID	22,714,215	8,629,946	22,991,914	47,402,472
75% LID	32,326,746	12,292,929	34,486,588	71,448,114
100% LID	38,815,401	14,751,738	42,245,022	87,670,535
Creekside recreation[a]	80,527,887	50,478,407	40,371,870	76,146,118

a. Applies to all LID options.

Table A.8. Summary of monetized recreational benefits under the LID CSO control options, over the 40-year project period (present value[a])

	Tacony	Cobbs	Schuylkill	Delaware
Non-creekside recreation				
25% LID	$4,499,951	$1,702,843	$2,456,977	$$4,684,956
50% LID	$16,028,916	$6,089,960	$16,224,881	$34,016,111
75% LID	$22,812,264	$8,674,846	$24,336,416	$51,271,313
100% LID	$27,391,163	$10,409,972	$29,811,370	$62,912,556
Creekside recreation[b]	$145,154,937	$94,100,602	$73,900,681	$138,970,735

a. Present value estimates presented in 2009 USD, assuming a 4% inflation rate and 4.875% discount rate.
b. Applies to all LID options.

A.5 Omissions, Biases, and Uncertainties

To estimate the total recreational benefits under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table A.9 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of recreational benefits.

Table A.9. Omissions, biases, and uncertainties

Assumption/methodology	Likely impact on net benefits[a]	Comment/explanation
Only "new" visits are included in the analysis	-	Our analysis only includes visits that would not have occurred elsewhere if the LID improvements had not been implemented. However, there is a marginal benefit associated with the trips that would have occurred in another location (or the individuals would continue to make trips to this location under the LID alternatives). Given the relatively low direct-use values, the exclusion of these benefits does not likely make a significant impact on overall benefits. Further, the percentage of total visits that are "new" is based on qualitative discussions and on-site visits. A degree of uncertainty surrounds these assumptions.

Table A.9. Omissions, biases, and uncertainties (cont.)

Assumption/methodology	Likely impact on net benefits[a]	Comment/explanation
Non-Philadelphia residents are not included in the analysis	+/++	The Parks Report includes park visitation data for Philadelphia residents only. Non-Philadelphia residents are therefore not included in our analysis due to lack of data on how often they visit Philadelphia Parks. Inclusion of these visitors would increase overall benefits, most likely in the Schuylkill and Delaware River watersheds, which have a more regional appeal.
Direct use values do not take into account the quality of the recreational experience	U	If the quality of recreational visits to CSO watersheds is higher (or lower) than for visits to an average park in Philadelphia, users might experience a higher (or lower) value per outing. Locational factors (e.g., proximity to existing parks or neighborhood demographics) may also affect the quality of the recreational experience.
The direct-use values used in this analysis are low compared to similar studies	+	The direct use values in the Parks Report are relatively low. However, in Philadelphia, recreational values are not expected to amount to as much as those in more remote areas. In the City, most people do not have to travel far to reach the parks, and residents spend a shorter time recreating once they get to the park. Further, based on qualitative descriptions of parks in the watershed, the quality of the experience seems to be lower than in other areas used in many valuation studies.
Analysis relies on average per-acre visitation estimates for all parks in Philadelphia	U-	Our analysis assumes that parks/recreational land in CSO watersheds support a certain percentage of recreational use of an average park in Philadelphia on a per-acre basis. This is based on on-site visits, review of park master plans, and discussions with park staff. Increasing/decreasing this assumption would impact net benefits. Locational factors (e.g., proximity to existing parks or neighborhood demographics) and the amount of contiguous land in improved areas may also affect per-acre use.
On-the ground implementation	U	There is a large degree of uncertainty surrounding planned activities under the LID options (e.g., location in the watershed) and how these activities will affect recreational use. It is therefore difficult to estimate the benefits associated with them. Our estimates are intended to provide an approximation of total benefits, based on our understanding of program implementation and the best available data for current recreational activity in Philadelphia.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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B. Property Values, as Enhanced by the LID Options

B.1 Summary

Residential property value benefits are calculated for properties within the four watersheds relevant to this analysis: Cobbs Creek, Delaware Direct, Lower Schuylkill River, and Tacony-Frankford Creek. Specifically, benefits are quantified separately for properties within PWD's combined sewer area and those outside of the area; and the analysis is limited to the City. Benefits to properties outside of the combined sewer area and within the Lower Schuylkill River Watershed are excluded from the analysis because this area already has a considerable amount of LID, including East and West Fairmount Parks, and we do not anticipate any significant additional benefits to properties in this area. An estimate is provided for each of the other seven geographic areas using a range of benefits found in the literature. These estimates are meant to account for benefits that accrue to property owners from implementation of the LID options, or a significant aspect of the LID options (e.g., trees), that are unique from other benefit estimates presented in this report. Estimates of property value benefits from the green infrastructure LID options are summarized in Tables B.1 through B.4. Details on the derivation of these estimates are presented below.

B.2 Data and Methods

Estimates are calculated using neighborhood-level property count and price data from the Philadelphia "NIS neighborhoodBase," a database of spatial and numerical data maintained by the University of Pennsylvania's Cartographic Modeling Lab (CML, 2005). The total number of properties within a watershed (both within and outside of the combined sewer area) is compiled using GIS data obtained on neighborhood boundaries, watershed boundaries, and combined sewer area boundaries. The neighborhood data contain census housing unit counts, which are used to aggregate counts over several neighborhoods within a given watershed.

Using 2007 median sales price data from the NIS neighborhoodBase, a weighted average market value is derived for properties sold within a given geographic area of interest (e.g., within the combined sewer area for a given watershed). Each neighborhood has a portion of the total properties sold for a given geographic area in 2007. Multiplying each of these neighborhood proportions by its median sales price for 2007 and summing over all neighborhoods, we derive a weighted average market value. Using the median selling price data helps to mitigate sensitivity to extreme selling prices, since only a fraction of properties sell within a given year. Moreover, if a certain type of property sold more heavily in 2007, relative to a historical baseline of sales by property type (e.g., condominiums vs. single family homes), the median will be less sensitive to this. It is for these reasons that median selling price is favored over the mean.

Table B.1. Summary of residential property value benefits from 25% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$16,162,924,000	$1,855,841,000	$18,018,765,000
Low-end estimate of one-time increase in residential property value for 25% LID	$161,629,000	$2,941,000	$164,570,000
Average estimate of one-time increase in residential property value for 25% LID	$282,851,000	$5,146,000	$287,997,000
High-end estimate of one-time increase in residential property value for 25% LID	$404,073,000	$7,352,000	$411,425,000

Table B.2. Summary of residential property value benefits from 50% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$32,325,848,000	$3,711,682,000	$36,037,530,000
Low-end estimate of one-time increase in residential property value for 50% LID	$323,258,000	$5,881,000	$329,140,000
Average estimate of one-time increase in residential property value for 50% LID	$565,702,000	$10,292,000	$575,995,000
High-end estimate of one-time increase in residential property value for 50% LID	$808,146,000	$14,703,000	$822,850,000

Table B.3. Summary of residential property value benefits from 75% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$48,488,771,000	$5,567,523,000	$54,056,294,000
Low-end estimate of one-time increase in residential property value for 75% LID	$484,888,000	$8,822,000	$493,710,000
Average estimate of one-time increase in residential property value for 75% LID	$848,554,000	$15,438,000	$863,992,000
High-end estimate of one-time increase in residential property value for 75% LID	$1,212,219,000	$22,055,000	$1,234,274,000

Table B.4. Summary of residential property value benefits from 100% LID program elements (2009 USD)

	Within combined sewer area	Outside combined sewer area	Total
Total residential properties	503,882	48,544	552,426
Weighted average median sales price	$128,307	$152,920	$130,470
Estimated total market value of affected residential properties	$64,651,695,000	$7,423,364,000	$72,075,059,000
Low-end estimate of one-time increase in residential property value for 25% LID	$646,517,000	$11,763,000	$658,280,000
Average estimate of one-time increase in residential property value for 25% LID	$1,131,405,000	$20,585,000	$1,151,989,000
High-end estimate of one-time increase in residential property value for 25% LID	$1,616,292,000	$29,407,000	$1,645,699,000

The literature suggests a range of benefits from green storm water infrastructure, or LID, from 0% to 7%. This implies the average property value will increase anywhere from 0% to 7% due to LID additions to the surrounding landscape. A further discussion of the literature is provided later in this appendix. For the calculations below, we tighten this range to 2–5% for properties within the combined sewer area, with a mean increase of 3.5%, given that most of the studies provide estimates within this inner range.

In the absence of spatial data that outline the specific location and magnitude of LID installments, we calculate total market value of affected residential properties under four LID scenarios: 25%, 50%, 75%, and 100% LID coverage. Under the 50% scenario, for example, the total market value of affected residential properties for a given area is calculated as 50% of the total number of properties in that area times its weighted average median selling price.

Given that LID will be implemented within the combined sewer area, properties in the near vicinity of these changes will capitalize the greatest benefit (i.e., those properties within the combined sewer area). However, properties outside the combined sewer area will arguably accrue some benefit, though perhaps at a diminished rate. A number of studies reflect this "decay" in benefit as distance from the amenity increases (see Correll et al., 1978; Tyrvainen and Miettinen, 2000; Morancho, 2003; Wachter and Wong, 2006). For properties outside the combined sewer area, we adjust the benefit estimates range downward from 2%–5% to 1%–2.5%. This downward adjustment reflects the decay of benefits as indicated by the literature. Calculations for properties both within and outside the combined sewer area assume benefits accrue uniformly among affected properties.

Property value estimates from the literature encompass a wide range of benefits associated with LID. Many of these are not distinct from other benefits presented in this report (e.g., anticipated energy cost savings are likely to be capitalized, to some extent, in the increased property values of tree-shaded properties). In theory, changes in property values should reflect associated differences in air quality, water quality, energy usage (often relating to heat stress), flood control, and perhaps other benefits (particularly those qualitative in nature). For example, a property in an area with good air quality should sell for a higher amount relative to another property in an area with low air quality, all else equal. Thus, to simply add property value benefits with the benefits from improved air quality would be double-counting. This applies to most benefit categories in this report. Therefore, only a portion of the literature estimates should be considered unique from other benefits in this report, such as those stemming from aesthetic improvements. To account for this, we adjust estimates from the literature downward by 50% to arrive at a range of 1–2.5% for properties within the combined sewer area and 0.5–1.25% for properties outside the combined sewer area.

Tables B.1 through B.4 show the projected benefits under the four LID scenarios, within and outside of the combined sewer area. Under each scenario, the total market value of affected properties is multiplied by the endpoints of the corresponding benefit estimates range, along with the mean. This yields aggregated benefit estimates for increases in property values. For example, the estimated average benefits for properties within the combined sewer area under the 50% LID scenario is a one-time increase of $565.7 million.

Total property value benefits range, on average, from $282.9 million to $1.13 billion for properties within the combined sewer area and between $5.1 and $20.6 million for properties outside the combined sewer area, depending on the LID scenario. This leads to a total estimate of average benefits ranging from $288.0 million for 25% LID to $1.15 billion for 100% LID.[1]

B.3 Literature Used in the Benefits Transfer

The "benefits transfer" methodology is used to calculate the above estimates. Due to the high costs of carrying out original research, primarily in terms of time, existing estimates for property benefits associated with LID or specific aspects of LID are applied to the Philadelphia context. As Sample et al. (2003) and Powell et al. (2005) point out, more research is needed in quantifying the benefits of LID; therefore, the pool of studies from which to choose is somewhat small. However, a number of studies were reviewed and six studies were selected as good candidates for a benefits transfer, given their similar context and scope. All six studies estimate a bundle of benefits associated with trees/LID/green storm water management in general. These studies are summarized in Table B.5. A brief summary is offered for each study, along with the estimate itself.

Table B.5. Studies used in benefits transfer

Study	Summary of study	Estimate (% increase in value)
Ward et al. (2008)	Estimates effect of LID on adjacent properties relative to those farther away, in King County (Seattle), WA.	3.5–5.0%
Shultz and Schmitz (2008)	Proxies LID effects by looking at differentials for neighborhoods with clustered open spaces and greenways, etc., in Omaha, NE.	Greenways: 1.1–2.7%; clustered open space: 0.7–1.1%
McPherson et al. (2006)	References an uncited study that looks at the differentials between properties with ample trees vs. none or few trees (few details).	3–7%
Wachter and Wong (2006)	Estimates the effect of tree plantings on property values for select neighborhoods in Philadelphia.	2% (intrinsic value of trees)
Anderson and Cordell (1988)	Uses sales data from Athens-Clarke County (GA) to estimate the value of trees on residential property. Looks at differences between houses with five or more front yard trees and those that have fewer.	3.5–4.5%
Braden and Johnston (2003)	Uses meta-analysis of studies to estimate several benefit categories related to on-site storm water retention (green approach/LID) for managing storm water.	0–5%

1. Watershed-specific estimates are provided in Section B.4.

B.4 Watershed-Specific Results

The tables that follow (Tables B.6 through B.12) show the property value results, by watershed and LID option. The benefit estimates reported here reflect the 50% reduction in increased property values described above, so as to focus on the aesthetic value of improvements provided by the added vegetation (i.e., reflecting a conservative approach to precluding possible double counting of energy savings and other benefits that might be embedded within the property value estimates).

Table B.6. Summary table of estimates (within combined sewer area; Tacony-Frankford Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$22,160,000.00	$55,399,000.00
50%	$44,319,000.00	$110,798,000.00
75%	$66,479,000.00	$166,197,000.00
100%	$88,639,000.00	$221,596,000.00

Table B.7. Summary table of estimates (within combined sewer area; Cobbs Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$7,010,000	$17,525,000
50%	$14,020,000	$35,049,000
75%	$21,030,000	$52,574,000
100%	$28,040,000	$70,099,000

Table B.8. Summary table of estimates (within combined sewer area; Delaware Direct Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$77,123,000	$192,808,000
50%	$154,246,000	$385,615,000
75%	$231,369,000	$578,423,000
100%	$308,492,000	$771,230,000

Table B.9. Summary table of estimates (within combined sewer area; Lower Schuylkill River Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$55,337,000	$138,342,000
50%	$110,673,000	$276,683,000
75%	$166,010,000	$415,025,000
100%	$221,347,000	$553,367,000

Table B.10. Summary table of estimates (outside combined sewer area; Tacony-Frankford Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$2,133,000	$5,333,000
50%	$4,266,000	$10,666,000
75%	$6,399,000	$15,998,000
100%	$8,532,000	$21,331,000

Table B.11. Summary table of estimates (outside combined sewer area; Cobbs Creek Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$81,000	$203,000
50%	$162,000	$406,000
75%	$244,000	$609,000
100%	$325,000	$812,000

Table B.12. Summary table of estimates (outside combined sewer area; Delaware Direct Watershed)

LID option (% increase)	Low % increase	High % increase
25%	$726,000	$1,816,000
50%	$1,453,000	$3,632,000
75%	$2,179,000	$5,447,000
100%	$2,905,000	$7,263,000

B.5 Omissions, Biases, and Uncertainties

To estimate property value benefits under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table B.13 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of property value benefits.

Table B.13. Omissions, biases, and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Focuses only on residential properties	++	Property values for commercial, industrial, and other non-residential properties are excluded from the analysis. Including the benefits to these properties would increase net benefits.
Based on benefits transfer approach, using range of 2–5%	U	The literature provides estimates for increases in residential property values from 0–7% due to LID implementation. We narrow this range to 2–5%. A Philadelphia-specific study, Wachter and Wong (2006), estimates the benefits to residential properties from tree plantings at 2%. Estimates used in this benefits transfer are assumed to be, on average, for a similar population and scale. Studies were chosen with these considerations.
Estimates are based on marginal changes to land market	U	Estimates used in the benefits transfer are based largely on hedonic analyses, which reflect benefits associated with marginal changes in a land market. We assume the aggregation of benefits over multiple properties around the City is a marginal change.
Reducing property value benefits to reflect potential double-counting	U	To avoid double-counting, we adjust property value benefits downward by 50%. This adjustment is ad hoc, but is used to estimate unique benefits to residential properties that are not estimated in other parts of the report. For example, enhanced aesthetics is a unique benefit, while reduced heat stress is not.
Number of affected properties	U	The number of residencies impacted depends on the LID option for which benefits are calculated. These range from 25%–100% as presented in Tables B.1–B.4.
Affected properties accrue benefits uniformly	U	All affected properties are assumed to accrue benefits uniformly. Considerations for baseline conditions or precise locations of LID implementations could not be made reliably in the absence of better data.

Table B.13. Omissions, biases, and uncertainties (cont.)

Assumption/ methodology	Likely impact on net benefits	Comment/explanation
Average property price is the weighted average of median prices from the affected neighborhoods	U, but small	The average property price for a given geographic area (used to derive total market value for that area) is calculated by taking the sales price for each neighborhood and multiplying by the share of residential properties sold within those neighborhoods, summing over all neighborhoods.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would probably increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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C. Heat Stress and Related Premature Fatalities Avoided

This appendix describes the methodology used to evaluate the benefits associated with the reduction in EHEs and heat-related fatalities under the LID CSO control options currently being considered by the PWD. Results of our analysis are also provided.

C.1 Introduction

EHEs have a well documented history of adverse public health impacts. Relatively recent demonstrations of this heat-health relationship include the loss of roughly 15,000 lives in France during the 2003 European EHE (Koppe et al., 2004; Valleron and Mendil, 2004) and over 700 deaths in Chicago, Illinois, in a July 1995 EHE (Kaiser et al., 2007). In addition to causing increased mortality, EHEs have also been associated with a range of morbidity impacts including increased emergency room use (NOAA, 1995) and hospitalizations (Semenza et al., 1999).

Philadelphia has its own tragic history of adverse public health impacts from EHEs. Notably, in 1991 and 1993, the county coroner determined EHEs were responsible for over 20 and 100 deaths, respectively (CDC, 1994; U.S. EPA, 2006). These findings drew significant attention to the heat-health relationship in Philadelphia and resulted in a number of formal responses including:

- The establishment of Philadelphia's Heat Task Force to help develop and implement EHE notification and response plans.
- Interest from the City in developing a meteorological warning system to predict when threatening conditions were expected. This ultimately led to the development of Philadelphia's Heat Watch Warning System, which predicts daily mortality increases based on forecast weather conditions (Kalkstein et al., 1996).

Concern about the heat-health issue continued to build and drive research from the late 1980s through the 1990s. A similar pattern developed with respect to examining how the urban environment can increase the severity and/or duration of residents' exposure to elevated temperatures. These associated health concerns, combined with interest in reducing the electrical demand within urban areas, helped spur research into what is commonly known as UHI issues, particularly the potential for different mitigation actions (U.S. EPA, 2008a). Within this field, one studied UHI mitigation strategy involves increasing the reflectiveness (i.e., albedo) of urban

surfaces and/or increasing the acreage of urban vegetation (e.g., Hudischewskyj et al., 2001; Sailor, 2003).

The LID CSO control options are expected to increase the City's vegetated acreage. Thus, the envisioned LID programs will mimic urban revegetation programs focused on addressing the UHI. As a result, the LID options are expected to generate ancillary health benefits by reducing urban summer temperatures.

This appendix first provides a summary of results from studies that have estimated urban temperature reductions associated with increasing urban vegetation. As described below, these results are used to define a range of plausible scenarios for how the increase in vegetated acreage under the LID CSO control options could affect urban weather conditions in Philadelphia. The meteorological changes defined in these scenarios are then used to estimate the potential benefit of the LID programs in terms of avoided heat-attributable deaths. The appendix concludes with a series of final comments and considerations including a review of potential omissions, biases, and uncertainties in the study methods and results.

C.2 Modeled and Predicted Urban Temperature Reductions from Increased Urban Vegetation

Complex spatial models have been used to estimate how increasing urban vegetation can affect solar energy absorption and ultimately local meteorological values such as temperature and humidity. In these applications, the study area is first divided into grid cells. Each grid cell is then assigned to a land category class that has its own unique combination of attribute values (e.g., solar reflectivity/absorption, moisture, roughness). The impact of a program that increases urban vegetation is then accounted for by recalculating and reassigning attribute values in cells where the policy would be implemented.

For example, in the simplest approach, each grid cell would be assigned to one of two land categories, nonvegetated or vegetated. A policy to increase urban vegetation would then describe a percentage increase in vegetation, for example, a 10% increase in the study area. To simulate the effects of this policy, a new set of attribute values would be calculated for all cells initially assigned to the nonvegetated category. These new attribute values would reflect a weighted average of the nonvegetated and vegetated attribute values. In this hypothetical scenario, the new attribute value in previously nonvegetated cells would now be equal to 90% of the original nonvegetated attribute value plus 10% of the vegetated attribute. Values for cells originally categorized as vegetated would remain unchanged in this example. The policy's impact on urban conditions is then calculated by running an urban meteorology model for the base case and the policy case and calculating the difference between meteorological values of interest (e.g., average daily temperature).

This approach has previously been used to estimate the impact of a 10% increase in urban vegetated acreage for a number of U.S. cities, including Philadelphia (Hudischewskyj et al., 2001; Sailor, 2003), over a limited number of days. In the Hudischewskyj et al. (2001) study, the modeling was limited to considering the period July 14–15, 1995. Sailor (2003) modeled a number of multi-day events from June through August 1991–2001. Table C.1 presents the results of both studies with respect to changes in various air temperature measures.

Table C.1. Summary of urban temperature impact results from increasing urban vegetation in Philadelphia

Study	Vegetation scenario	Modeled temperature change result (°F)	Notes
Sailor (2003)	10% increase in urban vegetation from increased deciduous broadleaf tree cover	0.39 (average temperature)	Average temperature is the average of hourly differences calculated from 8 a.m. to 7 p.m.
		0.49 (maximum temperature)	Maximum temperature is the difference between the maximum daily temperatures in the control and policy cases
Hudischewskyj et al. (2001)	10% increase in urban vegetation (type of vegetation not clearly specified)	0.70 (maximum temperature 7/14)	Difference in maximum surface temperatures in base and policy case
		0.40 (maximum temperature 7/15)	

The results in Table C.1 suggest that increasing vegetation by 10% in Philadelphia might reduce urban temperatures by between 0.40°F and 0.70°F depending on the temperature measure (i.e., maximum vs. average temperature).

A similar study (Columbia University Center for Climate Systems Research et al., 2006) evaluated a number of potential changes to the urban landscape in New York City. The study estimated that there would be a 0.40°F reduction in temperature at 3 p.m. in New York City if 6.7% of the total city area represented were to receive shading by adding trees along streets. The study also estimated a potential 1.10°F reduction at 3 p.m. if 31% of the city area were converted from its current mix of grass areas, streets without trees, and impervious roofs to areas with trees and living (i.e., vegetated) roofs.

C.3 The Meteorological Impact of the LID Scenarios

The green CSO compliance alternatives are expected to reduce daily maximum temperatures in the watershed area as a result of increased shading and replacement of dark paved surfaces with vegetation that absorbs less solar radiation. However, the increase in vegetated acreage is also expected to increase humidity due to increased evapotranspiration. Collectively, this would increase the dewpoint temperature.

Depending on the LID option implemented, the resulting increase in vegetated acreage would be equivalent to a 6% to 31% increase in vegetated acreage measured as a percentage of the original impervious acreage across all CSO areas in the watersheds. This is similar to how the vegetated acreage increase was measured in Sailor (2003). The vegetation increase under the LID options is also roughly equivalent to a 4% to 21% increase in vegetated area when measured as a percentage of the total area covered by combined sewers across all watersheds. This is similar to how the change in vegetation was measured in the Columbia University Center for Climate Systems Research et al. (2006) study.

Because the increases in vegetation planned for implementation under the LID options are similar to the increases in vegetation evaluated in Sailor (2003) and Columbia University Center for Climate Systems Research et al. (2006), we used these studies to estimate the meteorological changes that would occur under the LID options. Specifically, the values of the temperature reductions in the temperature-only scenarios in Table C.2 bound the temperature change results reported in these earlier studies (see Table C.1 and associated discussion). The scenario results that incorporate changes in temperature and dewpoint are intended to increase the overall reality of the LID option impacts by addressing the expected increase in the dewpoint with the additional vegetation while hopefully providing an additional set of realistic estimates for consideration.

Table C.2. Alternative heat and relative humidity scenarios for Philadelphia LID compliance heat-mortality modeling

Scenario	Reduction in daily max temperature (°F)	Increase in daytime dew point temperature (°F)
1. Temperature only: minimum	0.25	0.00
2. Temperature only: maximum	1.75	0.00
3. Temperature and relative humidity: minimum	0.75	0.25
4. Temperature and relative humidity: maximum	1.25	0.50

C.4 Estimating Future Health Benefits from Reduced EHE Temperatures in Philadelphia

Our current analysis reflects an expansion in scope from our previous work that estimated potential public health benefits for a program that reduced EHE-attributable health impacts in Philadelphia during selected EHEs, by increasing urban vegetation (based on Kalkstein and Sheridan, 2003). Because a similar method is used for this effort, we first begin this section with a review of Kalkstein and Sheridan (2003) to present critical methods. The rest of this section provides an overview of how the meteorological scenario changes for analyses selected in Section C.2 were applied to the available regionally downscaled climate change data and the associated heat-mortality calculation system encompassed in Philadelphia's Heat Health Watch Warning System.

C.4.1 A review of Kalkstein and Sheridan (2003)

Kalkstein and Sheridan (2003) used a five-step process to estimate how a hypothetical change in urban temperature could affect heat-attributable mortality by evaluating a subset of summertime days specifically selected because they represented EHE conditions. The study is particularly relevant because Philadelphia was one of the study cities evaluated.

In the first step, each selected day was assigned to an air mass category based on available meteorological data. Air mass categories characterize weather conditions based on the values for a set of meteorological variables including temperature, dew point, wind speed, and cloud cover. Specific air mass categories include:

- Dry moderate (DM): A warm, comfortable air mass that occurs in Philadelphia frequently in summer.
- Dry polar (DP): Cooler than DM, but still quite warm in the summertime. Usually occurs immediately after the passage of a cold front.
- Dry tropical (DT): The hottest air mass in the summer, with temperatures usually exceeding 95 degrees and sometimes topping 100. Little cloud cover and low humidity lead to potentially rapid dehydration.
- Moist moderate (MM): A cloudy, mild air mass that may sometimes be associated with fog and light rain.
- Moist polar (MP): Usually a winter, rather than summer, air mass, this situation is often associated with storms moving up the East Coast.

- Moist tropical (MT): Very warm and humid air mass, sometimes associated with summer thunderstorms. Sticky and uncomfortable, and quite common in summer.

- Moist tropical plus (MT+) and Moist tropical plus plus (MT++): These are particularly hot and humid subsets of the MT air mass. Dewpoint temperatures are very high, temperatures are in the 90s, and overnight temperatures are the warmest of any air masses. These hot, humid conditions have historically led to increased mortality in Philadelphia.

- Transition (T): Associated with a frontal passage, when temperature, dewpoint, and other meteorological factors are changing rapidly.

In the second step, the study days with offensive air masses are identified. In short, those air masses that have daily mortality values that are consistently larger than longer-term averages are labeled offensive. The identification of offensive air masses relies on the evaluating time series data over multiple years to evaluate the relationships between daily mortality totals and air mass categories. In Philadelphia, the offensive air mass categories include: DT, MT+, and MT++.

In the third step, the heat-attributable mortality for each offensive air mass day is calculated. These calculations are completed using mortality algorithms developed using an iterative process to identify the regression equation that provides the best explanation of the observed difference in mortality from the longer term trends (i.e., the heat-attributable mortality). In this iterative process, meteorological variables and factors such as the timing of the offensive air mass day within the summer season and the persistence of the EHE are evaluated as potential explanatory variables.

The fourth step repeats the process for the study day while also accounting for the predicted change in temperature as a result of the increased urban vegetation. In the fifth step, the difference in mortality from the two scenarios is calculated and reported to indicate the impact of the increased urban vegetation.

Kalkstein and Sheridan (2003) found that the impact of increased vegetation varied according to the EHE event, and often day-to-day. Overall, the study reported a net reduction in the estimate of heat-attributable deaths with the increase in urban vegetation. However, the mortality reductions were not evenly distributed across days and some days showed an increase in the mortality estimates. The strength of the conclusions and ability to generalize the results across longer time periods are constrained by the limited number of summertime days and EHEs considered.

C.4.2 New study of increased vegetation with climate change

To develop a more detailed assessment of the potential heat-health impacts of the LID scenarios, the possible changes in temperature and relative humidity presented in Table C.2 were evaluated using the same general approach as in Kalkstein and Sheridan (2003) and described above in Section C.4.1. However, because the LID programs are expected to take a number of years for the vegetation targets to be fully achieved, the meteorological data used for the evaluation was provided by regionally downscaled General Circulation Model (GCM) results from a compilation of the A1 family of climate change emissions scenarios.

The downscaled meteorological results are produced for each day, from April 1 through August 31, in a representative year using a deterministic method that incorporates linear monthly regressions to help adjust the GCM results and ensure the probability distributions for the values for a baseline period in the 1990s are generally consistent with observed values during this time. This approach has been used for similar assessments of potential future heat impacts (e.g., Hayhoe et al., 2004). To try and capture inter-annual variability and provide results at different points in the LID project lifecycle, downscaled results were calculated for two future decades: 2020–2030 and 2045–2055. To help provide a point of reference, similar calculations were made for the 1990–2000 period.

The results of this evaluation are presented in Tables C.3 and C.4 in terms of the estimated number of heat-attributable deaths and offensive air mass days in each decade using the downscaled GCM data alone (the *control* results), and when accounting for the temperature and dewpoint temperature changes being evaluated for the LID scenarios.

Looking at the results a number the general conclusions can be drawn:

- Any measurable cooling provided by implementing an LID scenario is likely to provide some reduction in EHE-attributable mortality
- EHE-attributable mortality reductions are roughly proportional to the relative magnitude of the assumed temperature change
- The health benefits of the LID scenario implementation are relatively constant across the different decades, comparing the lives lost in the scenario to the control with the exception of the 1.75°F temperature reduction which has a noticeable increase in lives saved moving from the 2020s to the 2045–2055 period
- EHEs are likely to become an increasing risk to public health in Philadelphia without continued adaptation.

Table C.3. Estimated heat-attributable deaths assuming alternative temperature and dewpoint impacts from LID options

Year	Control	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total surplus heat-related mortality													
1990	75	2020	90	85	66	79	75	2045	121	118	86	97	93
1991	70	2021	50	47	34	39	36	2046	117	114	90	102	94
1992	32	2022	52	48	36	41	38	2047	98	91	75	82	78
1993	47	2023	155	150	122	135	127	2048	94	87	64	78	70
1994	120	2024	128	122	105	112	109	2049	138	130	111	121	116
1995	53	2025	61	55	43	51	47	2050	85	79	62	77	69
1996	69	2026	98	95	74	83	79	2051	171	165	149	158	154
1997	93	2027	86	83	63	77	71	2052	72	63	47	56	50
1998	56	2028	54	49	41	46	45	2053	105	97	74	87	78
1999	116	2029	117	105	83	93	91	2054	89	87	73	82	77
2000	60	2030	47	45	33	40	37	2055	147	143	110	134	122
Mean	**72**	**Mean**	**85**	**80**	**64**	**72**	**69**	**Mean**	**112**	**107**	**85**	**98**	**91**

Table C.4. Estimated offensive air mass days assuming alternative temperature and dewpoint impacts from LID options in various time periods

Year	Control	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Year	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total number of offensive days													
1990	54	2020	59	56	49	53	52	2045	73	72	60	62	61
1991	44	2021	43	41	35	36	35	2046	62	62	53	59	55
1992	32	2022	37	35	32	33	32	2047	61	58	53	56	54
1993	33	2023	76	75	69	72	69	2048	57	54	44	50	47
1994	67	2024	61	58	55	55	55	2049	74	71	67	69	67
1995	44	2025	46	44	37	40	38	2050	56	53	45	53	46
1996	45	2026	62	61	52	56	54	2051	76	74	70	70	70
1997	51	2027	61	61	52	59	55	2052	47	44	35	40	35
1998	41	2028	38	35	32	33	34	2053	60	58	51	55	53
1999	64	2029	65	62	56	57	57	2054	55	55	49	52	50
2000	42	2030	42	42	37	39	38	2055	79	78	69	76	74
Mean	**47**	**Mean**	**54**	**52**	**46**	**48**	**47**	**Mean**	**64**	**62**	**54**	**58**	**56**

Underlying most of the mortality estimates and most of the summary results identified above is the actual mortality algorithm that was incorporated for the offensive air mass days. This algorithm is presented as Equation 1.

Equation 1. Daily heat-attributable mortality

Daily heat attributable mortality = $[-22.904+(1.79 \times DIS)+(1.198 \times Tmax) - (0.054 \times Julian)] / 4.722$

where:

DIS =	day in sequence value, where 1 is the first day of an offensive air mass, 2 is the second consecutive day, etc.
Tmax =	daily maximum temperature in °C
Julian =	time of year variable, with April 1 =1, April 2 = 2 … August 31 = 153
4.722 scalar **=**	adjustment value used so that the GCM 1990 control scenario mortality estimates match actual heat attributable mortality estimates for the decade.

The mortality algorithm shows why, because Tmax is the only meteorological variable in the equation, the mortality results can generally be sorted by in terms of the associated temperature changes. It also demonstrates why, with a coefficient value on maximum temperature of roughly 1, the results are generally proportional to the assumed temperature changes. However, this emphasis on the maximum temperature in the mortality algorithm overlooks that the assumed changes in dewpoint temperature do play an important role in the results as they influence the air mass categories a day is assigned to and thus, in some cases, whether it falls into an offensive or non-offensive category.

Perhaps the most important feature of both the mortality and EHE day estimates in Tables C.3 and C.4 is to note the significant variability within the year-by-year results for a scenario and across scenarios. Expressed as a percentage of the mean values for estimated EHE-attributable deaths, the standard deviation of the decadal results is roughly 45% in the 2020–2030 estimates and roughly 30% in the period 2045–2055. Within years, results for scenarios can be roughly 2–3 times as large when comparing the largest estimates to the smallest. In short, while the results show the benefits of pursuing an LID program in terms of reducing EHE-attributable mortality in Philadelphia, predicting the exact nature of benefits in any given time period is complicated and becomes increasingly uncertain if narrower time windows are considered.

C.5 Application to Philadelphia LID Option Scenarios

We used the temperature and relative humidity changes identified in Table C.2 to estimate changes in heat-related mortality under the LID alternatives. First, based on estimated increases in vegetated acreage, we assumed that Scenarios 1 and 3 represent a range of the changes that would occur under the 25% LID option. We also assumed that changes under the 100% LID option are best represented by Scenarios 2 and 4.

Based on these assumptions, we estimated the average number of lives each year, for three 10-year periods: 2020–2029, 2030–2039, and 2040–2049 under the 25% and 100% LID options. We then scaled the percent of benefits realized each year based on the timeline for program implementation provided by CDM and the effective tree model developed by Stratus Consulting (see Appendix H). We assume that no heat-reduction benefits are realized prior to 2020.

To estimate the number of lives saved under the 50% and 75% LID options, we scaled results for the 25% and 100% LID options based on the level (percentage) of LID for each option. We then estimated the monetary value associated with the number of lives saved under each LID option based on EPA's recommended VSL ($7,000,000). Table C.5 presents the results of this analysis on a City-wide basis.

Table C.5. City-wide benefits associated with reduced urban temperatures under the LID alternatives

CSO option	Number of lives saved, over 40-year period	Present value of lives saved (based on EPA's recommended VSL) (millions, 2009 USD)
25% LID	137	$739.4
50% LID	196	$1,057.6
75% LID	255	$1,375.9
100% LID	314	$1,694.1

To estimate benefits for each watershed, we allocated the City-wide estimates shown above based on watershed population. Table C.6 presents the present value benefits (for 40-year project period, 2009 USD) associated with reduced heat-related fatalities, by watershed.

Table C.6. Present value benefits associated with reduced heat-related fatalities under LID CSO options, allocated by watershed (millions, 2009 USD)

CSO option	% of total population in CSO watersheds	Tacony	Cobbs	Schuylkill	Delaware
25% LID	8%	$174.7	$62.8	$207.7	$294.2
50% LID	24%	$249.9	$89.8	$297.1	$420.9
75% LID	28%	$325.1	$116.8	$386.5	$547.5
100% LID	40%	$400.3	$143.8	$475.9	$674.2

C.6 Omissions, Biases, and Uncertainties Associated with Health Benefit Conclusions

The following sections provide a summary of the impact of critical assumptions and calculation approaches used to develop the results of this analysis.

C.6.1 Accuracy of any single temperature and dewpoint scenario result

Well-understood basic physical principles underlie the assumption that significantly increasing the vegetated acreage in Philadelphia through an LID program should reduce ambient temperatures and increase the relative humidity and dewpoint temperature. The extent of this change, however, is uncertain.

Past experiments calculate possible values using complex integrated models that also take the unrealistic step of instantaneously changing the nature of a significant portion of an urban area. The more realistic scenario is that these changes occur and are fully realized over time. What complicates calculating the associated impact of these changes is that they are also likely to be a function of other changes in the urban landscape. This uncertainty prevents assigning a likely direction of bias in the current estimates.

What the results and the mortality algorithm make clear though is that larger temperature reductions will, all else equal, increase the health benefit of LID implementation.

C.6.2 Uncertainty of climate change

Philadelphia has a long history of being adversely affected by EHEs. All else equal, climate change is likely to increase the public risks and impacts associated with future EHEs as shown in the results. However, while acceptance of climate change impacts continues to grow there is still considerable uncertainty over what the future climate will look like.

In particular, researchers have begun to note how several climate change-related impacts that were anticipated to begin appearing later in the century may have already begun and how the pace of climate change may be more rapid than previously anticipated. In this study, further warming would increase the number of EHE days. This would increase the mortality estimates across the control and LID scenarios and may have little impact on the estimate of lives saved with the LID scenarios. More importantly, increased warming could fundamentally alter the nature of the EHE-mortality relationship in Philadelphia. If tolerance/infrastructure thresholds are crossed in an increasingly warm climate before the population can adapt there is the chance that the mortality estimates presented could be conservative.

C.6.3 Changing population size, demographics and response to heat

Heat is a well-recognized public health threat in Philadelphia and the City has an active and aggressive education, notification, and response program to address EHE conditions. The current estimates assume that the future rate of EHE-attributable deaths in response to EHE conditions will remain unchanged. To the extent future heat programs become more effective or factors that make those most currently vulnerable to EHEs become less of an issue (e.g., better access and use of air conditioning), the current heat mortality estimates could be overstated. However, the potential benefits of the LID program, all else equal, could remain unchanged in this situation if the impact is relatively small. In addition, these estimates hold the City's population at a constant size for all time periods evaluated. The bias introduced as a result will result in an overstatement of impacts, all else equal, if the future population is expected to decline compared to 2000 levels. Results would similarly be understated if future populations are expected to grow relative to 2000 levels.

Heat has and will continue to be a public health threat in Philadelphia. By offering the potential to reduce urban temperatures, the envisioned LID scenarios directly address the fundamental nature of the risk associated with EHE conditions and hold the potential to help prevent lives being lost to future EHEs.

C.6.4 The benefits of nonfatal heat stress cases avoided are not included

This analysis has focused solely on the number of premature fatalities avoided due to the impact that LID options are projected to have on urban temperatures and heat stress deaths. The cooling anticipated from the green infrastructure approaches also will generate public health benefits for individuals who would otherwise suffer nonfatal heat stress-related episodes. For example, the LID approaches will reduce the number of nonfatal heat stress episodes, thereby reducing the pain, suffering, medical expenses, and other losses incurred by individuals who otherwise would have become ill or temporarily disabled by heat stress. Thus, the total anticipated value of reduced heat stress is underestimated here, because it focuses exclusively on mortality events and omits morbidity episodes.

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D. Water Quality and Aquatic Habitat Enhancements and Values

Under all of the CSO control options currently being evaluated by the PWD, water quality will be improved in streams and rivers within the City's CSO service area. Under the LID CSO options, stream restoration, wetlands, and increased vegetated area will also result in substantial aquatic habitat enhancements.

As described below, individuals in Philadelphia not only benefit from the direct use of these improved resources (e.g., through recreation), but also from knowing that these resources exist at a given level of quality. In environmental economics, this is referred to as "nonuse" value.

The following sections provide further background on nonuse values and outline Stratus Consulting's methodology for estimating nonuse values for improved water quality and aquatic habitat under the different CSO control options. Estimates for the benefits associated with these improvements are also provided.

D.1 Nonuse Values and Benefit Transfer

The different CSO control options yield different types and levels of water quality-related benefits. For example, stream restoration and water quality improvements under LID options will result in recreational benefits for many Philadelphia residents (see Appendix A). Recreational benefits accrue to individuals who actually participate in recreational activities, and are therefore quantified based on "use values" associated with different types of stream-side recreation.

For most residents in the greater Philadelphia area (including those who rarely or never participate in stream-related recreational activities), the different CSO control options will also result in some level of "nonuse" benefits. These nonuse benefits stem from the inherent value that individuals place on environmental goods and resources (in this case, water quality and habitat improvements). A frequently discussed basis for nonuse value is the desire to maintain the functioning of specific ecosystems.

In environmental economics, nonuse values are often referred to as existence and bequest values (King and Mazzotta, 2005). Existence value is the benefit generated today by knowing that a resource exists even if no use of the resource is anticipated. Bequest value is the value individuals gain from the preservation of the resource for use by their heirs. The term nonuse value is typically used in a more general manner to encompass both of these constructs (Harpman et al., 1994).

Nonuse values can only be estimated using techniques called "stated preference" methods. Contingent valuation (CV) has been the most commonly used stated preference method for estimating nonuse value, although more sophisticated variants (such as conjoint or choice set approaches) are now sometimes applied. In its simplest terms, CV is a survey-based technique used to elicit the maximum amount (in dollar terms) that an individual would be willing to pay for a resource (or an improvement to a resource) of a specified quality. Stated preference methods for conducting economic analysis are so named because values are obtained based on the stated preferences of individual survey respondents. An original stated preference study typically requires a significant amount of time and financial resources, because there are several important design and sampling features that need to be developed and pre-tested to ensure the reliability of the values derived from the survey instrument. For this reason, researchers often use the *benefits transfer* approach to estimate "willingness to pay" values.

Bergstrom and De Civita (1999, p. 79) offer the following definition of benefits transfer:

> Benefits transfer can be defined practically as the transfer of existing economic values estimated in one context to estimate economic values in a different context …. In the case of natural resource and environmental policies and projects, benefits transfer involves transferring value estimates from a "study site" to a "policy site" where sites can vary across geographic space and or time.

Benefits transfer is commonly used in economics, and there is a well-developed literature on how to correctly apply this method (e.g., Rosenberger and Loomis, 2003). Federal guidelines for economic analysis discuss how and when benefits transfer should be applied (U.S. EPA, 2000; U.S. OMB, 2003).

In the present case, we use benefits transfer to estimate average WTP per household in the greater Philadelphia Metropolitan Area (MA) for water quality and aquatic habitat improvements under each of the CSO control options. Our estimates are based on a meta-analysis, conducted by Van Houtven et al. (2007), of 131 WTP estimates from 18 studies (21 publications) conducted between 1977 and 2003. The WTP estimates included in the meta-analysis were all derived using stated preference methods.

D.2 Methodology

As noted above, to estimate WTP values for water quality and aquatic habitat improvements in Philadelphia, we relied on a meta-analysis of water quality valuation studies conducted by Van Houtven et al. (2007). A primary objective of the meta-analysis was to develop a tool (regression model), based on existing (primary) studies that could be used in benefits transfer analysis to predict WTP estimates for different policy scenarios. The following sections summarize the

methodology used to conduct the meta-analysis and the assumptions made to transfer results of the analysis to Philadelphia.

D.2.1 Meta-analysis: data collection and common influences on WTP estimates

The studies included in the Van Houtven et al. analysis were limited to stated preference studies conducted in the United States and to studies that described water quality in terms that could be converted to a common 10-point scale. Once studies that met these criteria were selected, the authors identified common variables across the studies that were likely to influence WTP estimates. In general, these variables can be categorized as follows:

- **The water quality "commodity."** The authors converted the water quality changes evaluated in each study into a common metric. To do this, they constructed a 10-point water quality index, WQI_{10}. This index is based in part on the water quality ladder (WQL) developed by Vaughan (1986) as a way of conveying water quality to the general public, particularly survey respondents. Vaughan defined the ladder such that, for example, a water quality index value of 2.5 (out of 10) was "boatable," 5.1 was "fishable," and 7.0 was "swimmable." Many researchers (e.g., Desvousges et al., 1987 and others) have used Vaughan's WQL to obtain WTP estimates for changes in the "steps" of the ladder. Van Houtven et al.'s WQI_{10} maps water quality characteristics not specifically related to recreational use (e.g., habitat suitability) to the WQL. Figure D.1 shows a schematic of Vaughan's original WQL. Table D.1 shows some specific water quality measures associated with the different use levels identified.

- **Study population characteristics.** WTP relates primarily to individuals' preferences, which are determined at least in part by personal characteristics. For example, individuals who are active recreational users of water resources are also likely to have stronger preferences for improving freshwater quality. Thus, users typically place higher values on water quality changes than nonusers, all else equal.

  Further, individual values for water quality changes reflect both their willingness and their ability to pay. The economic conditions that affect an individual's perceived ability to pay for water quality changes can be captured (at least in part) through personal or household income. If water quality is a normal good, then increasing income is expected to have a positive effect on WTP.

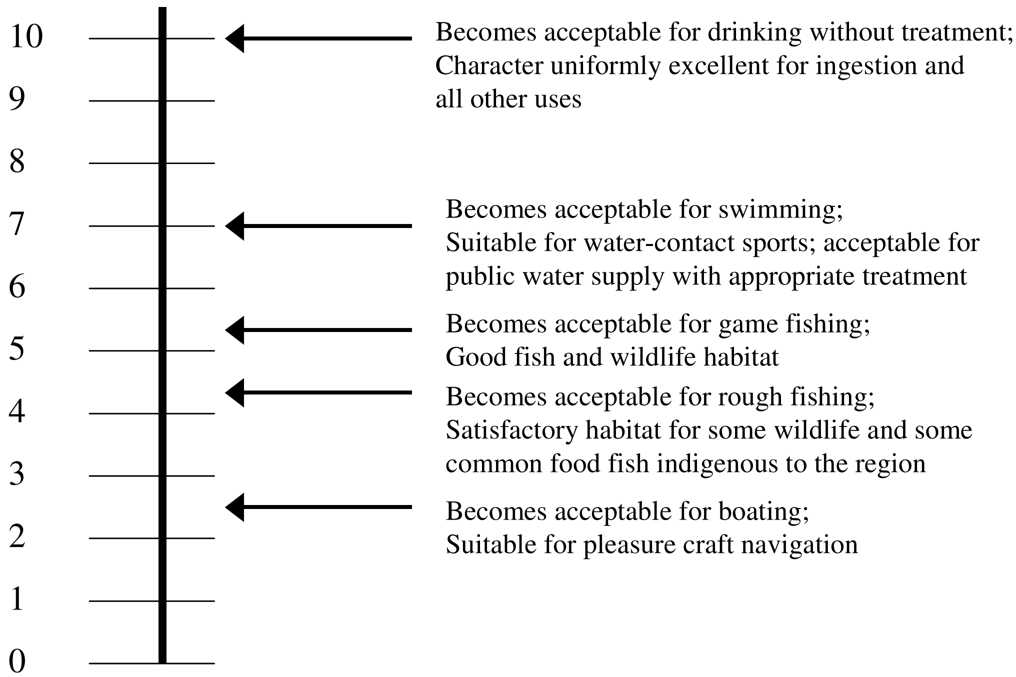

Figure D.1. Vaughan's (1986) water quality ladder.

Table D.1. Water quality characteristics for 5 classes of water use

	Fecal coliform (no./100 mL)	Dissolved oxygen (mg/L)	5-day BOD (mg/L)	Turbidity (NTU)	pH
Acceptable for drinking without treatment	0	7.0	0	5	7.25
Acceptable for swimming	200	6.5	1.5	10	7.25
Acceptable for game fishing	1,000	5.0	3	50	7.25
Acceptable for rough fishing	1,000	4.0	3	50	7.25
Acceptable for boating	2,000	3.5	4	100	4.25

Source: Russell et al., 2001.

- **Valuation method.** The magnitude of the value estimates for water quality changes is also expected to depend on the way in which the estimates were derived. As noted above, all of the WTP estimates included in the analysis are based on stated preference methods (either the CV method or conjoint analysis). However, a number of methodological differences have the potential to influence WTP. One potentially significant difference is the type of value elicitation format used (e.g., open-ended vs. dichotomous choice questions). WTP may also be influenced by whether the stated preference survey is conducted in person, over the phone, through a mailed questionnaire, or in another format. These variables are controlled for in the Van Houtven et al. (2007) analysis.

- **Other study characteristics.** WTP estimates may also be influenced by the overall quality of the methods and results of the study. Two potential indicators of study quality are the survey response rate and the publication outlet. Higher response rates and publication in peer-reviewed outlets are generally considered to reflect better quality studies. However, the publication selection process may result in estimation bias if, for example, reviewers and editors are more inclined to accept higher value estimates or if analysts are less likely to submit lower estimates (Stanley, 2001). Thus, while the expected effect of these characteristics on WTP is indeterminate, it is important to control for them in meta-analysis.

D.2.2 Meta-regression analysis

To evaluate societal preferences for water quality changes, Van Houtven et al. (2007) incorporated data from the 18 selected water valuation studies (based on the categories described in Section D.2.1 above) into a meta-regression analysis.

Table D.2 describes the specific variables used to estimate the author's final regression models. The two primary variables of interest are WTP2000 (dependent variable), which is the estimated mean WTP per household for a defined change in water quality [converted to 2000 dollars using the consumer price index (CPI)], and $WQI_{10}CHANGE$, which captures the corresponding change in water quality in terms of the WQI_{10}.

The authors estimated the model using three different functional forms – linear, semi-log, and log-linear. Although all three of these forms are reasonable for approximating the relationship between WTP and the other variables, the log-linear approach has at least two conceptual advantages. First, it implies that, as changes in water quality approach zero, WTP also approaches zero. Second, it implies that the *marginal* effect of a water quality change on WTP depends on income. The semi-log model shares this second advantage; however, it also implies that if WTP increases with larger improvements in water quality, then it does so at an increasing rate.

Table D.2. Variables included in Van Houtven et al. meta-regression analysis

Variable	Description
WTP2000	Annual WTP for water quality change (in 2000 dollars)
$WQI_{10}CHANGE$	Water quality change (based on 10-point WQI)
WQ_REC_USE	= 1 if the water quality change described in the study includes a reference to recreational use support (e.g., suitable for recreational fishing)
$WQI_{10}BASE$	Baseline level of water quality from which water quality improves
ESTUARY	= 1 if the water quality change occurs in an estuary
LOCAL_FWATER	= 1 if the water quality change is restricted to freshwater in the local area (i.e., within a single waterbody, county, or metro area)
MIDWEST	= 1 if the affected waterbodies are in the Midwest region of the United States
SOUTH	= 1 if the affected waterbodies are in the Southern region of the United States
INCOME2000	Average household income (in thousands of 2000 dollars)
INCOME_APPROX	= 1 if average household income was approximated based on local Census data
PERCENT_USER	Percent of the sample population that are users of the affected water resource
PUBLISHED	= 1 if the study is published in a peer-reviewed book or journal
OPEN_ENDED	= 1 if the value was estimated from an open-ended valuation question
RESPONSE_RATE	Response rate for the survey used in the study
IN_PERSON	= 1 if the survey used in the study was administered with an in-person interview
STUDY_YR73	= Year SP survey was fielded (minus 1973)

Source: Van Houtven et al., 2007.

Van Houtven et al. report two similar model specifications for each functional form. The first is a full model with all of the main explanatory variables included, while the second is a restricted model using a more parsimonious specification. The restricted models exclude variables that are not individually significant at 0.10 level or less (based on t-statistics). As shown in Table D.2, the dropped variables include ESTUARY, LOCAL_FWATER, MIDWEST, SOUTH, OPEN_ENDED, and the interacted variable for INCOME2000 and INCOME_APPROX. Due to their conceptual and economic importance in the model, all water quality variables were retained in the restricted models regardless of their statistical significance.

Table D.3 shows the results of log-linear (full and restricted) models estimated by Van Houtven et al. The log-linear model is shown because this is the functional form we decided to use for our benefits transfer analysis. Although the numbers presented below are not inherently intuitive (because they are in logged form), the magnitude and sign of the coefficients provide a relative idea of how the different variables influence WTP estimates.

Table D.3. Meta-analysis regression results

Variables	**Model coefficient (full model)**	**Model coefficient (restricted model)**
Ln(WQI10CHANGE)	0.343	0.358
Ln(WQI_{10}CHANGE)xWQ_REC_USE	0.414*	0.465**
WQI_{10}BASE	0.091	0.08
ESTUARY	0.025	
LOCAL_FWATER	-0.11	
MIDWEST	0.329	
SOUTH	-0.052	
Ln(INCOME2000)	0.964*	0.897*
Ln(INCOME2000)xINCOME_APPROX	-0.008	
PERCENT_USER	0.011**	0.011**
PUBLISHED	0.960**	0.898**
OPEN_ENDED	0.051	
RESPONSE_RATE	-0.014	-0.013*
IN_PERSON	0.315	0.43
STUDY_YR73	-0.041**	-0.029**
CONSTANT	-0.399	-0.227

Note: ** and * respectively denote statistical significance at the 5% (p = 0.05) and 10% level (p = 0.10).

Source: Van Houtven et al., 2007.

As shown in Table D.3, most variables included in the model have a positive influence on WTP estimates (e.g., an individual with higher income will report higher WTP) to relative degrees. The negative effect of STUDY_YR73 indicates that, controlling for income and price effects, estimates of average real (inflation-adjusted) WTP for water quality improvements has declined over time. It is possible that this decline reflects changes in preferences over time; however, it may also be the result of other factors, such as possible changes in publication selection processes (e.g., by authors or editors) or in estimation methods, that tend to favor lower WTP estimates.

The effect of RESPONSE_RATE is also negative. The authors report that although there are no strong priors for how response rates should affect the magnitude of WTP estimates, these results suggest that surveys with lower response rates might exclude individuals with lower average WTP for water quality improvements.

For benefits transfer, the model coefficients shown above are multiplied by their respective input variable (the value of which is determined by the specific policy scenario). The sum of these products is then used to estimate WTP2000. For example, WTP estimates for the restricted model would be calculated as follows:

$$
\begin{aligned}
Ln(WTP2000) &= -0.227 + (0.358 \times Ln[WQI10CHANGE]) \\
&+ (0.465 \times Ln(WQI_{10}CHANGE) \times WQ\_REC\_USE) + (0.08 \times WQI_{10}BASE) \\
&+ (0.897 \times Ln(INCOME2000)) + (0.011 \times PERCENT\_USER) \\
&+ (0.898 \times PUBLISHED) + (0.013 \times RESPONSE\_RATE) + (0.43 \times IN\_PERSON) \\
&+ (-0.029 \times STUDY\_YR73)
\end{aligned}
$$

D.2.3 Benefits transfer

As noted above, we used the log-linear model specification to predict WTP for the LID and non-LID CSO control options. We first estimated benefits associated with water quality/habitat changes under the 100% LID, 35’ Tunnel, and RTB HR01 alternatives. To estimate benefits associated with the less aggressive alternatives under each option (LID, Tunneling, Satellite Treatment), we scaled downwards based on the scope of the different alternatives. Further, we assumed the level of improvement under the Plant Expansion options to be equal to those of their corresponding LID component (e.g., benefits under the 100% LID + 215 MGD option will be the same as those estimated for the 100% LID option alone).

To provide a range of benefit values, we estimated results using both the full and restricted models from Van Houtven et al. We made the following assumptions in applying these models to Philadelphia:

- Benefits are estimated based on an average baseline water quality for all affected waterbodies (i.e., not by individual watershed). This is consistent with most studies included in the meta-analysis, which were conducted on a more regional scale. These estimates would be difficult to allocate across watersheds.

- We separately evaluate WTP per household for households within the City and households within the greater Philadelphia, MA but not within the City limits (including households in Bucks, Chester, Delaware, Montgomery counties). A number of factors led to this separate evaluation:

  - Households outside of the City have much higher incomes (on average) than households within Philadelphia. This affects WTP for water quality and ecological habitat improvements.
  - Distance from the water bodies being improved is expected to decrease WTP to some degree.

  - Households outside of the City are expected to have a much higher WTP for improvements in the Schuylkill and Delaware rivers (given their regional importance), as opposed to the more local Tacony and Cobbs creeks.
  - To account for these factors, we scaled WTP estimates for households outside of the City by 0.80 to account for distance and then multiplied these estimates by 0.61 (percent of CSO area stream miles in the Schuylkill and Delaware River watersheds).

- We assumed the baseline water quality in the affected streams and rivers (Cobbs Creek, Tacony Creek, and the tidal portions of the Schuylkill and Delaware rivers) to be 4.3 units. This score was determined based on knowledge of the WQI and affected streams. At 4.3, the water quality and habitat in the water body is assumed to support some "rough" fishing (not for game species), and is considered boatable.

- Under the 100% LID option, water quality is expected to improve by 2.5 units, up to 6.8. At this level, habitat (and fishing) is greatly improved but water quality levels do not allow for swimming.

- Under the most aggressive tunneling and satellite treatment options, water quality is assumed to improve by 1.2 units. This accounts for improved water quality but little change in aquatic habitat.

- In each case, we assumed that the stream restoration and water quality improvements will improve recreational opportunities in most areas (WQ_REC_USE equals 1). Although many residents do not use these areas for in-stream recreation, we can estimate the nonuse value they hold for these amenities.

- The variable PERCENT_USER is set at 0 because we are looking to capture only nonuse values in this part of the analysis.

- The variable INCOME_2000 is set at median household income for the City, which was estimated by the Census as $30,746 annually (lower than the 2000 national average). For households outside of the City but within the Philadelphia, MA, the model was estimated with INCOME_2000 equal to $64,736 (U.S. Census Bureau, 2000).

- The variables ESTUARY and LOCAL_FWATER were both set equal to 0.61 to reflect the percent of stream miles within PWD's CSO boundaries that are considered "tidal" rather than freshwater.

- The study year is assumed to be 2009.

- Finally, consistent with Van Houtven et al., PUBLISHED was set at 0.5 (due to the uncertainties regarding whether this variable reflects study quality or publication bias). All other variables related to study format were set at the Van Houtven et al. sample means.

Based on these assumptions, Table D.4 shows the inputs used for each CSO control alternative for WTP for households within the City.

Table D.4. Meta-regression analysis inputs for Philadelphia CSO control options

	Variable input LID option	Variable input non-LID option
WQI_{10}CHANGE	2.5	1.2
WQI_{10}CHANGExWQ_REC_USE	2.5	1.2
Ln(WQI10CHANGE)	0.916	0.182
Ln(WQI_{10}CHANGE)xWQ_REC_USE	0.916	0.182
WQI_{10}BASE	4.3	4.3
ESTUARY	0.61	0.61
LOCAL_FWATER	0.61	0.61
MIDWEST	0	0
SOUTH	0	0
INCOME2000	30.746	30.746
INCOME2000xINCOME_APPROX	30.746	30.746
Ln(INCOME2000)	3.426	3.426
Ln(INCOME2000)xINCOME_APPROX	3.426	3.426
PERCENT_USER	0	0
PUBLISHED	0.5	0.5
OPEN_ENDED	0.6	0.6
RESPONSE_RATE	58.02	58.02
IN_PERSON	0.31	0.31
STUDY_YR73	36	36

Based on these inputs, Tables D.5 and D.6 show the results of the meta-analysis. Table D.5 shows estimated WTP in the greater Philadelphia, MA (per household) for water quality improvements under the 100% LID and most aggressive non-LID options. Table D.6 shows total present value estimates (over the 40-year project time period) for all CSO options within each watershed.

Table D.5. Estimated WTP (per household and total annual) for water quality improvements under the 100% LID and most aggressive non-LID options

	WTP per household per year (full model)	WTP per household per year (restricted model)	Total annual WTP (full model)	Total annual WTP (restricted model)
100% LID option				
City/County of Philadelphia	\$11.48	\$18.28	\$6,774,451	\$10,791,199
Philadelphia, MA (excluding Philadelphia County)[a]	\$11.41	\$17.40	\$9,917,607	\$15,119,047
Total annual WTP			\$16,692,057	\$25,910,246
Non-LID (most aggressive options)				
City/County of Philadelphia	\$6.58	\$9.99	\$3,886,634	\$5,898,359
Philadelphia, MA (excluding Philadelphia County)[a]	\$6.55	\$9.51	\$5,689,925	\$8,263,918
Total annual WTP			\$9,576,559	\$14,162,277

Note: Based on 1,459,331 households in Philadelphia, MA (2000 Census). Values adjusted to 2009 current year dollars based on percent increase in CPI from 2000.

a. Scaled to account for distance from waterbodies and WTP estimates for Delaware/Schuylkill only.

To estimate total benefits associated with the 24 different CSO alternatives, we applied a scalar based on the scope of each option compared to the most aggressive LID, Tunneling, or Satellite Treatment option. Consistent with our analysis of other benefits, we allocated benefits over the 40-year project time period based on construction and implementation timelines provided by CDM. We assumed that stream restoration and riparian improvements would occur under all the LID alternatives (25%–100% LID Options). Thus, at each level of LID, 75% of the maximum water quality/ecological habitat benefits will be realized (as a result of the stream restoration program). The remaining 25% of maximum benefits will vary based on the level of LID implemented.

To estimate WTP for water quality and ecological habitat improvements for each watershed, we allocated total WTP for households the City by restored stream mile within each affected CSO area. For households outside of Philadelphia County, but within the greater Philadelphia, MA, we allocated total WTP by restored stream mile within the Schuylkill and Delaware River CSO watersheds only. Thus, we assume \$0 WTP by these households for improvements to Tacony-Frankford and Cobb creeks.

Table D.6. Total WTP in the Philadelphia, MA for water quality and ecological habitat improvements under different CSO control options (present value 2009 USD)

	Tacony	Cobbs	Schuylkill	Delaware
LID options/Transmission and new treatment capacity with LID component[a]				
25% LID	$21,576,660	$27,912,663	$78,631,310	$178,551,447
50% LID	$23,664,723	$30,613,888	$86,240,792	$195,830,619
75% LID	$25,752,787	$33,315,114	$93,850,273	$213,109,791
100% LID	$27,840,851	$36,016,339	$101,459,755	$230,388,963
Tunnel options[b]				
15' Tunnel	$6,646,639	$8,598,429	$24,230,834	$55,021,981
20' Tunnel	$8,862,185	$11,464,573	$32,307,779	$73,362,642
25' Tunnel	$11,077,731	$14,330,716	$40,384,724	$91,703,302
30' Tunnel	$13,293,277	$17,196,859	$48,461,668	$110,043,963
35' Tunnel	$15,508,824	$20,063,002	$56,538,613	$128,384,623
Transmission and satellite treatment options				
25 Ofs	$15,508,824	$20,063,002	$56,538,613	$128,384,623
10 Ofs	$8,840,029	$11,435,911	$32,227,009	$73,179,235
4 Ofs	$2,481,412	$3,210,080	$9,046,178	$20,541,540
1 Ofs		$642,016	$2,985,239	

a. Analysis assumes that transmission treatment options will be combined with LID components to reach target level of water quality associated with each LID option.
b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28, and 31'.

Table D.6 shows total WTP (in present value terms) in the greater Philadelphia, MA (including Philadelphia City/County) for water quality and ecological improvements under each CSO control option. The benefit estimates shown below reflect total WTP based on the average WTP estimates per household as reported in Table D.5. Total benefits also reflect the aggregation of WTP by households within the City and those outside of the City but within the Philadelphia, MA.

D.3 Sensitivity Analysis

Stratus Consulting conducted a sensitivity analysis to evaluate how WTP per household fluctuates in response to changes in baseline water quality and the level of water quality/habitat improvement (as defined by the WQ_{10}). The results of this analysis (as summarized in Table D.7) indicate that within the reasonable range of assumptions related to these variables, WTP per household does not vary wildly as these inputs change but seem to follow a reasonable progression. WTP is more sensitive to the actual improvement in water quality as opposed to the baseline index value used in the analysis.

Table D.7. Summary of sensitivity analysis of household WTP for water quality improvements

				Household WTP within Philadelphia		Household WTP within Philadelphia, MA	
Scenario	**Baseline WQI**	**Increase in WQI**	**Endpoint WQI**	**Full model**	**Restricted model**	**Full model**	**Restricted model**
1	4.3	2.5	6.8	$11.48	$18.28	$23.39	$35.65
2	4.3	1.9	6.2	$ 9.32	$14.59	$19.00	$28.44
3	4.8	2	6.8	$10.14	$15.84	$20.67	$30.88
4	4.8	1.4	6.2	$7.74	$11.81	$15.78	$23.02
5	5	1.8	6.8	$9.54	$14.75	$19.44	$28.77
6	5	1.2	6.2	$7.02	$10.57	$14.30	$20.61
7	4.3	1.2	5.5	$6.58	$9.99	$13.42	$19.49

Numerous studies have examined water quality issues using a variety of techniques including CV (Hurley et al., 1999; Loomis et al., 2000; Whitehead, 2000; Stumborg et al., 2001; Eisen-Hecht and Kramer, 2002; Brox et al., 2003; Collins et al., 2005). To further validate our results, we reviewed many of these studies in order to obtain a range of current estimates. However, we found very few studies that evaluated water quality improvements within a context similar to the Philadelphia policy case. Very few studies have been conducted in urban areas and most studies include use values, as well as non-use values, in the stated WTP. The estimates for WTP per household reported in Table D.5 therefore reflect the lower end of the range of WTP values reported in most studies. However, we feel that these estimates represent a reasonable WTP per household.

D.4 Omissions, Biases and Uncertainties

In the absence of site-specific data, it was necessary to make a number of assumptions in order to estimate WTP per household for water quality and habitat improvements under the CSO control options. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table D.8 provides a summary of these assumptions and uncertainties and their likely impact on total benefits.

Table D.8. Omissions, biases and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Analysis of improvements in the Schuylkill and Delaware River watersheds include households in the Philadelphia, MA region (i.e., more than City residents).	--	The inclusion of households in Bucks, Chester, Delaware, and Montgomery counties substantially increases total WTP due to (1) the large number of households in these counties, and (2) the high average income of households in these counties, which is correlated with estimated WTP. In contrast, households in the City have a relatively low average income and, thus, a lower estimated WTP for water quality/habitat improvements. No adjustment is made to WTP estimates for these households even though they do not live close by. A distance adjustment would serve to decrease overall benefits.
In the absence of a study specific to the Philadelphia area, we relied on a meta-analysis of WTP for water quality/habitat improvements to estimate total benefits.	U	There are limitations of using the meta-regression model as a benefits transfer tool. For example, results provide very limited evidence about how WTP is related to the spatial characteristics of water quality changes. The meta-regression does not measure how WTP varies with respect to the proportion or amount of waters that are improved or the distance of the water quality changes from populations. This lack of specificity imposes limitations on the precision of policy-relevant benefits transfer, since policies almost always impact waterbodies in spatially non-uniform ways.
There are uncertainties surrounding the baseline WQI and estimated improvements under CSO options.	U	It is difficult to estimate the WQI index improvements in each watershed under the different CSO options. However, as demonstrated through sensitivity analysis (see Table D.7), this is not likely to have a significant impact on total benefits within the reasonable range of WQI estimates. Additionally, we currently assume that the Transmission/Treatment options combined with the LID options, will not achieve water quality and habitat benefits beyond those that would be achieved through the implementation of LID alone. Revising this assumption would serve to increase total benefits.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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E. Wetland Enhancement and Creation

As described in the main body of this report, PWD is currently evaluating a number of LID options for controlling CSO events. A major component of these LID alternatives is an aggressive stream restoration program intended to improve water quality and aquatic habitat within affected streams. As part of the stream restoration program, PWD has planned for the enhancement and creation of a number of wetlands within each of the CSO watersheds.

Long regarded as wastelands, wetlands are now recognized as important features in the landscape that provide numerous beneficial services to people and to fish and wildlife. Some of these services include improved water quality, groundwater recharge, shoreline anchoring, flood control, and habitat for species. In addition, wetlands, like other natural resources such as streams and lakes, can provide positive amenity values for nearby residents. These include open space, enhanced views, increased wildlife, and a buffer against noise and other forms of pollution.

Increased awareness of the value of wetlands has resulted in a number of studies to determine the value of their services. However, determining the value of individual wetlands is difficult because they differ widely and do not all perform the same functions or perform functions equally well. Further, a number of factors can influence how a wetland is valued, including wetland size, location, surrounding environment, characteristics of the surrounding population, and others.

Despite these uncertainties, we provide estimates for the benefits associated with the enhancement and creation of wetlands in the CSO watersheds under the LID CSO options. Our analysis is based on a review of the wetland valuation literature. As shown below, our per-acre benefit estimates represent the lower end of the range from most studies. This is because many of the benefits associated with wetlands are captured in the other analyses described in this report (e.g., recreation and water quality – to some extent).

The following sections provide a summary of Stratus Consulting's approach to assigning a value (or range of benefits estimates) to the wetlands planned for implementation as part of the LID CSO control options. The results of this analysis are also provided.

E.1 Acres of Wetlands Planned

The first step to this analysis was to determine the number of wetland acres that would be restored or created in each of the CSO watersheds. For the Schuylkill and Delaware River Watersheds, this information was provided by PWD and CDM.

To obtain estimates for planned wetland acres in the Cobbs Creek Watershed, we relied on a November 2008 report provided by CDM: "Cobbs Creek: A Gateway to Many Places and to Cleaner Water." This report was completed by CDM in partnership with PWD.

In the absence of specific data for Tacony-Frankford Creek, we determined the number of wetland acres per restored stream mile in Cobbs Creek and applied that ratio to the number of restored stream miles planned for the Tacony-Frankford.

Table E.1 presents the number of wetland acres planned for enhancement/creation in each CSO watershed as part of the LID CSO stream restoration program.

Table E.1. Wetland acres restored and created under LID CSO options

	Tacony-Frankford	Cobbs	Schuylkill	Delaware
Wetland areas in need of vegetative enhancement (acres)	8.4	9.7		26.7
Wetland creation (acres)	26.3	30.3	30.1	61.3
Total acres (may not add due to rounding)	34.8	39.9	30.1	88.0

E.2 Wetland Value

To assign a range of per-acre values to the wetland acres planned for enhancement or creation, we conducted a literature review of wetland valuation studies. Although a number of these studies have been conducted, we did not find any studies that could be directly applied to the Philadelphia policy case. Very few valuation studies have been conducted in urban areas. In addition, many studies include very high per-acre or WTP estimates based on services that will not be provided by the relatively small number of wetland acres planned in Philadelphia (e.g., flood control is not a relevant service anticipated from the wetlands created or enhanced in this study area).

As described below, we therefore relied on estimates from two meta-analyses to obtain an average value per wetland acre. This approach allows us to provide a reasonable, yet conservative estimate for specific wetland functions.

E.2.1 Brief review of wetland valuation literature

The range of estimates associated with wetland valuation studies is remarkable. For example, Woodward and Wui (2001) report per-acre values from 39 different studies ranging from $5 to $1,877 (updated to 2009 USD). In a recent meta-analysis, Borisova-Kidder (2006) estimated per-acre values for wetlands in different regions of the United States ranging from $93 to $1,935 (2009 USD). The meta-analysis incorporated 72 separate observations of wetland value from 33 studies.

A broad range of valuation methodologies has been applied to value wetlands. The method most commonly used in the literature has been to observe the market prices of products related to wetland services and then ascribe the total revenue from the sale of such products as the value of the wetland (Brander et al., 2003). This methodology is not applicable to the situation in Philadelphia, where the wetlands planned for implementation are not expected to provide market-related products to any extent.

The contingent valuation method (CVM) (see Appendix D) has also been widely used. For example, a common method is to use a hypothetical referendum, where households are asked if they would vote in favor of a particular resource protection action, if it cost their household $X. The amount of $X varies across households, so that a demand curve can be traced. From this demand curve, WTP is calculated. WTP values are commonly reported in dollars per year (or per month or other specified period of time) per household.

As expected, different valuation methodologies have been applied to value different wetland services. For example, CVM, hedonic pricing, and the travel cost method (TCM) have been applied to value amenity and recreational values. Replacement cost has largely been used to value the role of wetlands in improving water quality, and the production function approach has been used to value the habitat and nursery services of wetlands. Further, wetland values have been reported in the literature in many different metrics, currencies, and referring to different years (e.g., WTP per household per year, capitalized values, marginal value per acre).

To exemplify the differences and range of value estimates associated with wetland valuation studies, Tables E.2 and E.3 present some observations from the literature.

Table E.2. Examples of values of wetlands

Value (April 2009 USD)	Description	Source
$14,047 per wetland acre	Using a discount rate of 3%, this study estimated that present values per wetland acre are: commercial fishery = $846; trapping = $401; recreation = $181; storm protection = $7,549; total of these values = $8,977/acre (1983$).	Costanza et al., 1989
$74 annually per household	This study examined what Ohio residents were willing to pay for increased protection of wetlands of the Maumee River and Western Lake Erie basins in Ohio.	De Zoysa, 1995
$10–$38 per household per year	This study estimated WTP for wetland preservation benefits in western Kentucky.	Dalecki et al., 1993
$1,392 per acre per year for 30 years ($381,401 per acre over 15 years)	This study estimated economic benefits of wetlands for wastewater treatment use, in terms of savings over conventional wastewater treatment methods.	Breaux et al., 1995
$8 and $27 annually per household	This study estimated WTP for preserving the Clear Creek wetland in western Kentucky.	Whitehead and Bloomquist, 1991
$169–$2,688 per acre lump sum	Values reflect the range of restoring wetlands from croplands, by estimating easement costs, restoration costs, and the present discounted value of perpetual crop production.	Heimlich, 1994
$106–$164 annually per respondent	Values reflect what respondents are willing to pay for protection of wetlands in New England.	Stevens et al., 1995
$56 annually per household	This study is a meta-analysis of 30 studies. The largest mean WTP by wetland function was in terms of flood control ($84), with the smallest for water generation ($20).	Brouwer et al., 1997
$657–$11,830 per acre for residents of the drainage basin, and from $9,463 to $80,380 across residents of the State of Michigan.	The study estimated wetland benefits for Saginaw Bay, Michigan.	Cangelosi et al., 2001
$4–$1,877 per acre annually	The predicted values per acre of single-service wetlands range from $4 for presence of amenities to $1,868 for presence of birdwatching opportunities, with most services having predicted values in the $275–$600 range (see Table E.3 for breakdown of all values).	Woodward and Wui, 2001
$93–$1,935 per wetland acre	This range of values is from a meta-analysis of 72 observations of wetland values from 33 studies. This range represents predicted values for different regions in the United States.	Borisova-Kidder, 2006

Table E.3. Per acre annual values of wetland services

Service	Mean value per acre[a] (April 2009 USD)
Flood	$641
Quality	$681
Quantity	$207
Recreational fishing	$583
Commercial fishing	$1,270
Bird hunting	$114
Bird watching	$1,978
Amenity	$5
Habitat	$498
Storm	$387

a The predicted values are obtained at the means of year and acre variables. It must be emphasized that the values do not represent marginal values and cannot be summed to obtain the value of multiple function wetlands.

Source: Woodward and Wui, 2001.

E.2.2 Applying wetland value estimates to PWD's LID options

As noted above, we relied on two meta-analyses to estimate the value of the wetlands planned for implementation under the LID CSO control options. The meta-analyses allowed us to assign a per-acre value to area of wetlands within each watershed.

The first analysis was conducted in 2006 by Borisova-Kidder as part of a Master's thesis. All of the studies included in this analysis (1) evaluated wetlands within the United States, and (2) allowed for the calculation of wetland value on a per-acre basis. Based on this criteria, the meta-analysis incorporated 72 separate observations of wetland value from 33 studies. The studies include 22 journal articles, seven research reports or academic papers, two chapters in a book, one PhD dissertation, and one Master's thesis.

Rather than apply the results of Borisova-Kidder's meta-regression analysis, which allows for valuation of wetlands with only one primary function (e.g., flood control, recreation), we use the average value of the 72 estimates included in the study. This amounts to about $303.38 per acre in 2009 USD (adjusted from 2003 USD based on the CPI). We applied this value to obtain a lower bound estimate for the value of each new acre of wetlands created. For restored wetlands, we used half of this amount, or $151.69 (2009 USD).

As an upper bound for per-acre value estimates, we relied on the results of Woodward and Wui's (2001) meta-regression analysis of the value of a single service wetland. Woodward and Wui's analysis focuses on two types of variation in wetland values: deviations from the valuation function due to bias or errors in estimation, and variations along the valuation function attributable to different wetland characteristics (e.g., whether it is suitable for flood control, habitat, water quality). These factors were controlled for through a number of variables included in the regression analysis (e.g., through dummy variables for wetland services as well as the valuation method).

The dependent variable in Woodward and Wui's regression model is the natural log of the value per acre of wetland converted to 1990 dollars. In addition to the variables discussed above, the regression analysis includes variables for the year the study was conducted, whether the wetland was a coastal wetland, whether the value was an estimate of producer's surplus, and whether the results had been published. Three additional dummy variables were included in the analysis to indicate whether the data, theory, or econometrics used in the study were deemed highly questionable (see Woodward and Wui, 2001, for more detail).[1]

The results of the meta-analysis are shown in Table E.3. As an upper bound for the value of wetlands in Philadelphia, we applied the value estimate for a single service wetland providing habitat. We chose to use the single service value for habitat because it represents a middle ground for the single service wetlands evaluated and it excludes values that are accounted for in other areas of our analysis (e.g., recreation) or that are not applicable to the Philadelphia policy case (e.g., flood control). As shown in Table E.3, Woodward and Wui estimate that the value of a single service wetland providing habitat amounts to about $498 per acre (2009 USD). To value restored wetlands (as opposed to newly created wetlands), we applied half this amount on a per-acre basis.

Based on the values described above, Table E.4 shows the range of annual benefit estimates for the new and restored wetlands planned under the LID options within each watershed. Present value estimates for the 40-year project period are also provided. These values were obtained based on the stream restoration timeline provided by CDM. The stream restoration program is expected to be fully implemented by 2025.

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1. The authors recognize that important variables that determine a wetland's value are omitted from their model. For example, characteristics of the population near a wetland are particularly likely to influence the value placed on the area. However, such data could not be identified in most of the studies included in the analysis and these types of variables were therefore not included in the model. According to the authors, while the absence of these variables no doubt diminishes the explanatory power of the analysis, it need not bias the estimated coefficients if these variables are uncorrelated with the included set (Kennedy, 1986).

Table E.4. Total benefits provided by wetland services under LID options (2009 USD)

	Total annual wetland benefits (range of estimates assuming full program implementation)		Present value wetland benefits (range of estimates)	
Delaware River (tidal wetlands)				
Wetlands restored	$4,055	$6,657	$97,320	$159,751
Wetlands created	$18,585	$30,507	$445,910	$731,964
Total commitment	$22,640	$37,164	**$543,230**	**$891,715**
Schuylkill River (tidal wetlands)				
Wetlands created	$9,134	$14,994	$219,170	$359,769
Total commitment	$9,134	$14,994	**$219,170**	**$359,769**
Cobbs Creek				
Wetlands restored	$1,465	$2,405	$35,157	$57,711
Wetlands created	$9,183	$15,074	$220,335	$361,681
Total commitment	$10,649	$17,480	**$255,492**	**$419,392**
Tacony-Frankford Creek				
Wetlands restored	$1,276	$2,094	$30,608	$50,243
Wetlands created	$7,991	$13,117	$191,728	$314,723
Total commitment	$9,267	$15,211	**$222,336**	**$364,966**

E.3 Omissions, Biases, and Uncertainties

Although the economic literature on wetland valuation is relatively expansive, very few wetland valuation studies have been conducted in urban areas on wetlands similar to those planned for implementation in Philadelphia. We therefore relied on two meta-analyses reporting wetland value on a per-acre basis. Table E.5 identifies the key issues and uncertainties associated with this approach.

Table E.5. Omissions, biases, and uncertainties

Assumption/methodology	Likely impact on net benefits[a]	Comment/explanation
Wetland valuation studies are remarkably diverse in terms of the values obtained, the wetlands evaluated, and the characteristics of the studies.	U	Although we use an average estimate, as well as an estimate derived through meta-regression analysis, the characteristics of the wetlands in Philadelphia may be quite different than those of wetlands included in the base estimates. This could serve to increase or decrease overall benefits depending on the nature of these characteristics, however, we feel our estimates provide a reasonable range of benefits per acre given that they are intended to exclude the more "high-dollar" benefits associated with wetland services such as recreation and flood control.
The wetlands planned under the LID CSO control options are smaller in size than wetlands evaluated in most studies (and are not contiguous).	U	It is difficult to determine how this might impact overall benefits. On one hand, the scarcity of wetlands in the City may result in a higher value associated with them. On the other hand, larger wetlands can often provide additional ecosystem benefits that cannot be supported by wetlands of smaller size.
Our benefits transfer does not take into account demographic characteristics of surrounding communities.	-	Several of the wetland valuation studies included in the two meta-analyses are based on household WTP estimates, which are almost always correlated with average household income of the study population. Given the relatively low average income of households in Philadelphia (e.g., compared to the national average), the inclusion of demographic characteristics would likely slightly decrease the overall benefits.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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F. Poverty Reduction Benefits of Local Green Infrastructure Jobs

Benefit-cost analysis of public infrastructure investment projects does not traditionally consider job creation as a category of project benefits. Although creating jobs is universally perceived as beneficial, it is reasoned that jobs created by public investment are no more beneficial than jobs created by the private sector.

A public investment project must be funded with revenues drawn from the private sector – in this case, from PWD rate revenues collected from customers. If these funds were instead allowed to remain in private hands and be used for other private purposes, it is argued that an equivalent level of jobs would be supported. Stated another way, any jobs created by public investment are generally created at the expense of jobs in the private sector, so there is no net benefit in the overall level of employment arising from public expenditures (instead, under normal conditions, there is simply a transfer of employment across locations and sectors).

The only exception to this reasoning is the special case of a severe economic downturn in which private demand is so depressed that job creation is more assured through public expenditures. Despite the fact that recent economic events actually reflect this special case, the approach adopted here does not attempt to evaluate benefits of job creation in that context. Instead, we examine the value of specific types of job opportunities created within a certain socioeconomic niche.

In the popular media, "green jobs" or "green collar jobs" are described as encompassing many diverse job categories that have a bearing on environmental improvement in one way or another. In contrast, this analysis focuses only on the unique character of jobs created in the construction and maintenance of green infrastructure systems installed for purposes of urban stormwater management as part of an aggressive campaign to transform urban landscapes and neighborhoods. "Green infrastructure jobs" as defined here are essentially landscaping jobs, suitable for unskilled laborers and requiring no experience. There are significant social benefits that result from creating these specific types of jobs in an urban setting as part of a greening campaign. Such jobs can serve as a crucial stepping stone out of poverty for otherwise unemployed persons who reside in the very same neighborhoods in which the greening is targeted. The stabilizing and transforming effects of the green infrastructure on these neighborhoods reinforces and supports the benefits of providing employment to this population that is outside the labor force and trapped in poverty.

Traditional infrastructure – consisting of multi-billion dollar concrete tunnels – produces no such benefits. When the large construction contractors engage in large-scale traditional infrastructure projects, they have pre-negotiated labor agreements with all of the appropriate trade unions that enable them to expedite the project with no obstacles to obtaining the required labor when and where it is needed. For the most part, traditional stormwater infrastructure requires skilled laborers such as those represented by the trade unions. As implied by their status as union members, these are also people who are already in the labor force. When a city water department implements a traditional infrastructure project in this manner, the net effect is just to bid these already employed workers away from other construction projects.

This appendix presents some additional background on the connections between green infrastructure and poverty. The methodology employed in evaluating the poverty reduction benefits of "green infrastructure jobs" is described, and results are summarized and discussed.

F.1 Urban Poverty and Green Infrastructure

Most large older cities have been faced with long-standing problems in coping with poverty in their midst. Philadelphia is a typical example, as made clear in results of the U.S. Census Bureau's 2005–2007 American Community Survey (U.S. Census Bureau, 2008).

- Median household income in 2007 was $34,767 in Philadelphia, compared to $50,007 for the nation as a whole – 30% less household income at the median.
- Using a household income of $25,000 per year as a measure of poverty status, there were 212,093 households below this level in Philadelphia in 2007 – 38% of all households in the City. Nationally, the proportion of households with incomes below $25,000 per year was 25%.
- In Philadelphia, 57.8% of people over age 16 were in the labor force, compared to 64.7% for the nation as a whole.

Cities incur many types of costs in coping with poverty. Many types of assistance programs are supported to help people in poverty. But one of the greatest expenditure categories is unfortunately coping with crime, for which the poverty trap is a major causative factor. In this regard, Philadelphia is incurring relatively high costs (Heller, 2008).

- Philadelphia has the highest incarceration rate of any big U.S. city. The recidivism rate is 80% and the annual cost per inmate is among the highest at $30,000 per year.
- The City spends about $1 billion per year on the criminal justice system, which is about a quarter of the City budget.

The growing movement to transform urban landscapes with green infrastructure in the name of stormwater management and energy conservation holds the promise of a number of spillover benefits in reducing poverty. The installation and maintenance of green infrastructure requires large amounts of unskilled labor in what is essentially landscaping work. Large amounts of the work is to be performed in neighborhoods where many unemployed and relatively unskilled people live in poverty. Moreover, the transforming effect of green infrastructure on these neighborhoods can provide a foundation to stabilize troubled communities, reduce crime rates, and set a course for further progress against poverty. In the words of a leading green infrastructure activist, "If you give opportunities to the young men and women of this community to support themselves and their families, the need to build a jail goes away" (Carter, 2007).

Proof of these broader spillover benefits of green infrastructure is provided in the experience of the "Weed and Seed" program of the Community Capacity Development Office of the U.S. Department of Justice (U.S. DOJ, 2009). Launched in 2003, this program is now being demonstrated in 300 sites across the country. The strategy involves a two-pronged approach: law enforcement agencies and prosecutors cooperate in "weeding out" violent criminals and drug abusers, and public agencies and community-based private organizations collaborate to "seed" much-needed human services, including prevention, intervention, treatment, and neighborhood restoration programs. Through coordinated use of federal, state, local, and private-sector resources, neighborhood restoration strategies focus on economic development, employment opportunities for residents, and improvements to the housing stock and physical environment of the neighborhood. In the period between 2003 and 2006, major crimes decreased 2% within Weed and Seed areas (Baker, 2009).

F.2 Estimating Poverty Reduction Benefits of "Green Infrastructure Jobs"

The methodology for estimating benefits of "green infrastructure jobs" is based on the expectation that providing such jobs to unskilled residents within the targeted neighborhoods will provide these individuals with an important stepping stone on the path out of poverty which would not otherwise exist. The presence of the green infrastructure in these neighborhoods will enhance the opportunity for community stabilization and recovery that can further support progress against poverty.

As discussed above, society spends large amounts every year in its efforts to cope with the effects of poverty. If PWD chooses an LID approach to CSO control providing "green infrastructure jobs" to unskilled and unemployed residents who are currently living in poverty, they will be less impoverished and impose a lower level of societal costs. If PWD chooses a

traditional infrastructure approach, the jobs created will be much less likely to be filled by unskilled workers who are currently not in the workforce, yielding no benefits in reducing the societal cost of poverty.

The benefits of "green infrastructure jobs" are estimated by multiplying the total number of jobs created by an assumed per-employee amount of societal costs that will be avoided due to the altered poverty status of the new employee. The number of labor hours required for construction and maintenance of the LID alternatives was estimated as part of the engineering cost analysis. It is further assumed that one-quarter of these hours will be supervisory positions and therefore less likely to result in the hiring of unskilled and otherwise unemployed people. The avoided societal cost of poverty per non-supervisory employee used to value this benefit is estimated to be about $10,000 per year. This figure is derived from a review of different sources, as described below.

A 1993 analysis produced by the Institute for the Study of Civic Values reviewed local budget data sources for Philadelphia and produced an estimate of the total public cost of poverty shown in Table F.1. This estimate seems low because it does not include an element relating to coping with crime.

Table F.1. Estimate of the cost of poverty in Philadelphia

Element	Estimated annual cost (1992 USD millions)
Income, Medicaid, food stamps	1,000
Health and social services	400
Public housing	150
Community development	100
Homeless expenditure	15
Education	200
Total	**2,000**

Source: Schwartz, 1993.

A 1998 analysis by Wharton researchers also employed a bottom-up approach to identify direct poverty related expenditures in the City's 1996 budget amounting to about a billion dollars (Summers and Jakubowski, 1996). This study left out additional costs of crime and education, although acknowledging their potential significance. It also omitted direct expenditures by the Federal government that were estimated to be on the order of another billion dollars by Schwartz.

In a landmark study in the mid-1990s, econometric research was applied to a survey of U.S. cities and demonstrated statistically that a high incidence of urban poverty not only increases direct poverty expenditures of city governments, but also significantly increases the cost of many other seemingly unrelated city services (Pack, 1998). Applying the approaches of Summers and Jakubowski as well as those of Pack to the Philadelphia 2009 city budget, implies that as much as $3.5 billion of the $4 billion total is attributable to poverty. That total still omits additional direct poverty related outlays in Philadelphia by the Federal government.

A top-down national analysis of the "avoidable costs of poverty" was developed in a study prepared for the Entergy Corporation (Oppenheim and MacGregor, 2006), yielding the estimates shown in Table F.2.

Table F.2. National estimate of the avoidable costs of poverty

Element	Description	Estimated annual cost (2005 USD millions)
Crime	Cost of criminal activity, including property losses, costs of the judicial and correctional system, and security costs.	660,791
Health	Costs of health care, including costs that are preventable by improving health care and costs of low-income health care that are spread through society.	335,841
Unemployment/ underemployment	Costs of unemployment and underemployment, including unemployment compensation, job training, and the multiplier effects of lost economic activity.	222,492
Anti-poverty investments	Costs of current anti-poverty investments, including costs for social services, elderly services, income supports, affordable housing, food, education, energy and utility supports, and block grants for community services and community development.	270,053
Total		**1,489,178**
Source: Oppenheim and MacGregor, 2006.		

Another top-down analysis developed by the Center for American Progress (Holzer et al., 2007) produced a national estimate of the cost of poverty from a different perspective. Their approach was to compute the costs to society resulting from having children grow up in poverty. They focused on the individual as a means of capturing both lost economic productivity and additional costs associated with higher crime and poorer health later in life. Although this is a different approach to the analysis, it covers many of the same impacts in arriving at an estimate of the total cost of poverty. They summarize their results in terms of the net impact on the U.S. Gross Domestic Product (GDP), as shown in Table F.3.

Table F.3. Economic costs of poverty in the United States

Element	Estimated annual cost (% of GDP)
Foregone earnings	1.3
Crime	1.3
Health	1.2
Total	**3.8**

Source: Holzer et al., 2007.

Their indicated percentage of GDP attributable to poverty (3.8%) translates into a national cost estimate of about $500 billion per year which is only about one-third the national cost estimate developed in the previously discussed study for the Entergy Corporation. The differences lie in the approaches used to assign part of the cost of crime to poverty and also in the lack of accounting for the costs of social assistance programs in the work by the Center for American Progress which the Entergy study showed to be 18% of the total. In addition, the authors of the Center for American Progress study stressed that it was their very deliberate analytical objective to produce a lower bound estimate of the cost of poverty. In contrast to their results, another interesting study of the cost of poverty in Ontario (Laurie, 2008) produced an estimate that poverty expenditures accounted for between 5.5 and 6.6% of the provincial GDP.

The Philadelphia region (including the suburbs) is the fourth largest urban area in the United States in terms of GDP (PricewaterhouseCoopers, 2006). Apportioning the $500 billion national estimate from the Center for American Progress study on the basis of the Philadelphia share of national GDP yields an estimate of the cost of poverty to the region of $12 billion per year. Apportioning the $500 billion instead on the basis of the share of the nation's low-income households that lie within the City yields an estimate of about $3 billion per year. If a higher percentage of GDP (e.g., ~6% found in Ontario) is applied, the Philadelphia share of the $500 billion would be closer to $5 billion per year.

This latter range of "top-down" estimates is similar to the $2.0 to $3.5 billion per year range derived from the several "bottom-up" estimates for Philadelphia described earlier. However, the bottom-up studies mostly omitted direct Federal expenditures. The Entergy study described above is judged to provide the most complete top-down estimate of the total annual cost of poverty in the United States. Apportioning their $1.5 trillion per year national estimate on the basis of the share of the nation's low-income households that lie within the City yields an estimate of about $9 billion per year.

In estimating the spillover benefits of "green collar jobs" in reducing the costs of poverty, it is assumed that currently unemployed people living in poverty would be hired into the unskilled, non-supervisory positions. By the latest Census figures, there are about 227,500 such people residing in the City. If the $12 billion per year estimate of the cost of poverty is correct, it implies an annual cost of $57,000 per unemployed person in Philadelphia. An estimate of $9 billion per year implies about $45,000 per unemployed person per year. An estimate of $5 billion per year implies $25,000 per unemployed person per year. An estimate of $3 billion per year implies $15,000 per unemployed person per year.

The benefit assumed here is $10,000 per year in offsets to all the societal costs of coping with poverty. Hence an estimated savings of $10,000 per year is multiplied times the number of work years in "green infrastructure jobs" provided by each LID option.

F.3 Results

Table F.4 presents a summary of the total number of work years in "green infrastructure jobs" provided by each of the LID options in each watershed over the 40-year implementation period. Table F.5 presents a similar summary of the total present value (over 40 years) of the avoided societal cost of poverty attributable to the provision of these "green infrastructure jobs."

Table F.4. Total work years in "green infrastructure jobs" provided by LID alternatives

LID %	Delaware	Schuylkill	Cobbs	Tacony	Totals
25	3,341	1,607	476	1,490	**6,914**
50	7,379	3,535	1,050	3,303	**15,266**
75	11,307	5,409	1,608	5,040	**23,364**
100	14,778	7,081	2,105	6,590	**30,554**

Table F.5. Total present value (2009 USD millions) of "green infrastructure jobs" provided by LID alternatives

LID %	Delaware	Schuylkill	Cobbs	Tacony	Totals
25	28	13	4	12	**57**
50	60	29	9	27	**125**
75	93	44	13	41	**192**
100	121	58	17	54	**251**

F.4 Omissions, Biases, and Uncertainties

The analysis of poverty reduction benefits of "green infrastructure jobs" is straightforward; multiplying the number of work years provided times the estimated amount of avoided social costs. The basis for the estimate of the societal costs of poverty is the largest area of uncertainty in this procedure, as described further in Table F.6.

Table F.6. Omissions, biases, and uncertainties affecting valuation of "green infrastructure jobs"

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
It is assumed that LID options can be implemented in a manner that makes most non-supervisory "green infrastructure jobs" available to the target population.	-	If it is not possible to make many of the "green infrastructure jobs" available to the target population of unskilled and otherwise unemployed people living in poverty, then the spillover benefits of poverty reduction will be correspondingly reduced. We have assumed 75% of the job hours can be targeted to the relevant population.
The estimated value of the societal costs of poverty is supported by only a half dozen studies that were designed for different purposes.	U	Despite extensive research on poverty, the total social cost of poverty is not as well studied as a concept. We found only a few studies. Although they seem to bound a roughly comparable overall order of magnitude, confidence would be enhanced if there were a few more estimates to draw from.
It is assumed that the societal costs of poverty are reduced by $10,00 if a targeted recipient obtains a "green infrastructure job."	U	There is evidence that an unskilled job, alone, is inadequate to boost a person out of poverty. A skilled job is required. Thus, "green infrastructure jobs" are just a stepping stone on the path out of poverty. We assumed a $10,000 reduction in the avoided societal costs of coping with poverty.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would probably increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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G. Energy Usage and Related Changes in Carbon and Other Emissions

This appendix provides a summary of Stratus Consulting's approach for estimating the net energy use, and associated external costs, of the CSO control options currently being evaluated by the PWD. As described below, we have identified several key categories related to energy use (and associated emissions) for quantitative assessment, including:

- Electricity and natural gas savings due to cooling effect under the LID CSO control options
- "Wasted" fuel consumed by vehicles stuck in traffic delays caused by construction and maintenance activities
- Resulting energy costs and/or cost savings
- Carbon emissions/offsets associated with energy use (including fuel used by construction and maintenance vehicles) and/or savings under each option
- Estimated social value of carbon emissions and/or savings
- NO_x and SO_2 emissions/offsets, and associated health costs, related to energy use and/or savings under each option.

The following sections identify key inputs and assumptions used in our analysis and describe the general methodology employed to evaluate energy-related benefits and external costs. Final results for each CSO watershed are also presented.

G.1 Key Inputs and Assumptions

To estimate the energy-related benefits and external costs under each CSO control option, we employed standard industry methodology. In the absence of specific data, it was also necessary to make a number of assumptions based on our understanding of the different program components. Key inputs and assumptions are detailed below. Individual assumptions related to specific program components are provided in subsequent sections.

- **Energy costs.** To estimate the monetary benefits of electricity and natural gas savings under the LID options, we used PECO estimated electricity rates and natural gas rates provided by CDM ($0.10/kWh and $0.0135/MM Btu, respectively). The electricity rates

used in this analysis are relatively conservative. Section G.4.2 discusses how our overall results change as electricity rates are increased. To estimate the cost of additional fuel consumed in construction -related traffic delays, we assumed a cost of $2.50 per gallon of gasoline.

- **Energy-related emissions factors.** We evaluate emissions of CO_2, SO_2, and NO_x associated with net energy use under each CSO option. To do this, we use average air pollution emission factors for the State of Pennsylvania's electricity sector [in terms of tons of emissions per megawatt hour (MWh); EIA, 2007]. When the specific generating plants cannot be determined for an electricity grid like Philadelphia's, these estimated emissions are used at the state or regional level. The EIA estimates that Pennsylvania's CO_2 emission factor is 0.574 MT/MWh. SO_2 and NO_x factors at Pennsylvania power plants are estimated at 0.0041 and 0.00076 MT/MWh, respectively. To estimate emissions related to the use of natural gas, we use the CO_2 emission factor of 0.0527 MT of CO_2/MM Btu (EIA, 2007).

- **Social cost of carbon**. Another input used for this analysis is the dollar value assigned to GHG emissions, measured in CO_2e. The social cost of carbon is estimated as the aggregate net economic value of damages from climate change across the globe, and is expressed in terms of future net benefits and costs that are discounted to the present (IPCC, 2007). The most recent IPCC Assessment Report contained peer-reviewed estimates of the social cost of carbon. The IPCC found an average value of $12 per MT CO_2, but added that the range around this mean is large. For example, in a survey of 100 estimates, the values ran from USD $-3 per MT CO_2 up to $95 per MT CO_2. The often-cited Stern Review on the Economics of Climate Change estimates a social cost of carbon at $85 per MT CO_2 (Stern, 2006).

  For this analysis, the IPCC's average value of $12 was used when calculating social benefits and costs, which produces conservative estimates for the benefits and costs associated with GHG emissions (a conservative estimate). To determine total costs over the 40-year project period, we escalated the social cost of carbon by 2.4% per year,[1] above the general rate of inflation.

- **Cooling effect and carbon sinks of green infrastructure**. To estimate the benefits associated with the cooling effect and carbon sinks under the LID options, we relied on previous studies by the U.S. Department of Agriculture (USDA) Forest Service. The Urban Forest Effects Model (UFORE) provides estimates of energy savings via shading

1. The United Kingdom has established an official estimate of the social cost of carbon for use in many of its project evaluations and models the growth rate of the cost at 2.4% per year.

of trees and insulation by green roofs. It also provides carbon storage and sequestration data by species of tree. For our research, we used one type of tree of average size and average storage capabilities for all the cooling and carbon sinks. We also assumed that 30% of trees planted would be close enough to buildings to provide shading. Our results can easily be adjusted for specific species of trees.

- **Engineering estimates versus external costs**. The amount of energy required for excavation and other construction activities serves as a key input into our analysis. However, the costs associated with this energy use (i.e., electricity costs and the cost of fuel for construction and maintenance vehicles) are not included in our estimate of total benefits and external costs. The cost of energy used for these purposes is assumed to be included in the engineering cost estimates for each CSO option. However, we estimate and include the external costs associated with the energy consumption [e.g., CO_2, sulfur oxides (SO_x), and NO_x emissions and costs].

G.2 Methods

G.2.1 Estimating the external costs of traditional infrastructure CSO control options

We first estimated total energy use (electric and gasoline) under each of the non-LID CSO control options. Total electrical energy use was calculated based on power requirements for excavation, building, equipment, and pumping, as provided by CDM. Total fuel use was determined based on the estimated number of vehicle miles traveled (VMT) by construction and maintenance vehicles throughout the course of the project. Total fuel use also took into account the additional fuel used by individuals traveling on Philadelphia roadways as a result of construction-related traffic delays (see Appendix I).

Based on estimated total energy use, we were able to estimate total NO_x, SO_2, and carbon emissions (and associated monetary costs) under each CSO option. The individual components of our analysis are described below.

Emissions associated with energy used for excavation, building, equipment, and pumping. CDM provided estimates of the power needed for excavation, building, equipment, and pumping under each of the traditional infrastructure CSO control option (i.e., tunneling, plant expansion, and satellite treatment). We used these inputs to estimate total emissions generated under each option.

To determine total carbon emissions, we used average air pollution emission factors for the State of Pennsylvania's electricity sector (0.574 MT of CO_2/MWh) (EIA, 2007). We applied these

estimates to total power use required under each option. The monetary cost of these emissions was then estimated based on IPCC's average estimate for the social cost of carbon ($12/MT).

In addition to carbon emissions, we also evaluated the SO_x and NO_x emissions associated with electricity use under the different CSO control options. This analysis was also based on average air pollution emission factors for Pennsylvania power plants (EIA, 2007). We applied these emission factors (0.00414 MT SO_2/MWh and 0.000766 MT NO_x/MWh) to total electricity use under each option.

We then estimated the human health costs of SO_2 and NO_x emissions based on EPA-generated national averages. These estimates reflect the change in health risks, and associated values, of a typical ton of emissions for each pollutant (U.S. EPA, 2008b). They do not reflect only benefits in the local area, but take into account long-range transport of the pollution (emissions in one location spread over a wide area).

EPA estimates that the health-related costs of SO_x emissions from electricity-generating sources ranges from $25,234 to $53,985 per ton. For NO_x emissions, these costs range from $2,681 to $5,733 per ton. To determine total costs of SO_x and NO_x under the CSO control options, we applied the midpoints of these estimates to total emissions.

It should be noted that the power requirements provided by CDM for excavation, building, and equipment were provided as totals over the 40-year period, and the power requirements for pumping were provided as annual estimates. It is difficult to estimate energy-related costs far into the future due to a number of significant variables. These include a change in the generation mix for electricity, a change in retail energy prices, changes in both the social costs of carbon emissions and air pollution, and the change in the price of carbon emissions under a federal or regional carbon policy.

Emissions associated with fuel used by heavy construction vehicles. To evaluate fuel use and emissions associated with construction activities, we relied on CDM's estimate for the number of heavy-duty truck trips under each CSO control option. We estimated the total gallons of diesel fuel consumed by heavy-duty trucks based on an average distance of 20 miles per truck trip and an average mile per gallon of 6.6 (U.S. EPA, 2007).

We then calculated CO_2, SO_x, and NO_x emissions associated with heavy-duty vehicles based on emission factors for heavy-duty trucks (lbs CO_2/mile) as determined by the South Coast Air Quality Management District (SCAQMD, 2007). The social cost of carbon was used to measure the costs of carbon emissions from these truck trips. For SO_x and NO_x emissions, we applied the midpoint of EPA's estimates for health-related costs of SO_2 and NO_x from mobile sources. EPA's estimates range from $13,200 to $28,264 and $4,357 to $9,350 for SO_x and NO_x, respectively.

Emissions associated with fuel use by concrete delivery trucks. To determine the external costs associated with heavy-duty trucks used to deliver concrete materials, we used the same approach mentioned above. Because the number of concrete trucks under each option was not an input provided by CDM, we assumed the number of these trucks to equal half of the number of heavy-duty trucks used for excavation and construction.

Concrete manufacturing. One of the most energy-intensive industrial processes in the world is the production of cement, a key ingredient in the large amounts of concrete used in construction of traditional CSO infrastructure. The cement manufacturing process uses both electricity and a significant amount of fossil fuels directly in a heating process. While the direct energy costs of cement manufacturing do not affect this benefit-cost analysis, the carbon and air pollution costs that result do play a role. We were able to analyze the energy used and resulting carbon emissions and air pollution that result from this process.

First, using the total cubic feet of concrete (an input provided by CDM), we estimated the amount of cement used for each non-LID scenario based on standard concrete-cement conversion methods. We estimate the energy and emissions associated with the cement manufacturing process for each of the non-LID scenarios based on standard energy/emissions factors (Worrell and Galitsky, 2004, and as described above).

Traffic disruption. Under all of the CSO control options, construction and maintenance activities will cause traffic delays on Philadelphia roadways. There is an increase in fuel use associated with these delays due to increased time spent idling and traveling at slower speeds. The methods used to estimate additional fuel used as a result of construction-related delays are detailed in Appendix I. However, actual fuel use and associated costs are reported in the energy use/cost category in Tables G.1 through G.8.

We used standard emissions conversion factors, as described above, to estimate tons of CO_2, SO_x, and NO_x emitted into the atmosphere as a result of this additional fuel use.

G.2.2 Estimating the external costs and benefits of green infrastructure

Emissions associated with energy used for excavation. Similar to the traditional infrastructure options, the LID options will require large amounts of power (electricity) to excavate areas for LID coverage. This input was provided by CDM. We use the same methods as described above to estimate the external costs of emissions associated with this energy use.

Emissions associated with fuel used by construction and operation vehicles. For the development of green infrastructure, heavy-duty vehicles will be needed during the construction process. For the LID options, we used the same techniques and assumptions described above to estimate emissions associated with these vehicles. As part of this analysis, we also included the

emissions generated by operations and maintenance vehicles. For these trucks, we assume an average truck trip of 15 miles and an average mile per gallon of 20.2.

Table G.1. Energy-related benefits and external costs of CSO control options in the Tacony-Frankford Creek Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction benefit (cost of increase)
LID options			
25% LID	$2,994,995	$4,380,801	$2,022,051
50% LID	$7,274,893	$9,989,179	$4,574,863
75% LID	$10,164,800	$13,920,497	$6,955,968
100% LID	$12,671,820	$17,492,296	$8,790,891
Plant expansion options (excluding LID component)[a]			
215 MGD	($32,635)	($240,406)	($36,526)
298 MGD	($37,299)	($262,233)	($41,239)
490 MGD	($55,050)	($600,679)	($79,752)
820 MGD	($81,063)	($840,455)	($120,971)
Tunneling options			
15’ Tunnel	($124,142)	($4,127,396)	($469,015)
20’ Tunnel	($194,652)	($5,461,468)	($644,125)
25’ Tunnel	($286,028)	($ 6,988,847)	($851,115)
30’ Tunnel	($401,457)	($8,781,757)	($1,098,570)
35’ Tunnel	($538,551)	($10,722,019)	($1,376,390)
Satellite treatment options			
25 Ofs	($ 2,152)	($108,395)	($12,248)
10 Ofs	($8,748)	($443,600)	($49,884)
4 Ofs	($36,550)	($1,945,197)	($212,250)
1 Ofs	($104,928)	($5,620,441)	($608,916)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.2. Energy-related benefits and external costs of CSO control options in the Cobbs Creek Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$956,469	$1,399,034	$645,753
50% LID	$2,323,278	$3,190,101	$1,461,008
75% LID	$3,246,186	$4,445,589	$2,221,428
100% LID	$4,046,817	$5,586,264	$2,807,421
Plant expansion options (excluding LID component)[a]			
63 MGD	($17,580)	($363,341)	($60,090)
233 MGD	($19,353)	($497,537)	($73,871)
404 MGD	($19,851)	($539,720)	($82,551)
Tunneling options			
15’ Tunnel	($189,398)	($2,946,459)	($409,049)
20’ Tunnel	($265,640)	($3,918,187)	($558,469)
25’ Tunnel	($389,503)	($5,202,623)	($771,474)
30’ Tunnel	($513,954)	($6,450,870)	($979,242)
35’ Tunnel	($661,099)	($7,745,230)	($1,206,602)
Satellite treatment options			
25 Ofs	($1,500)	($113,581)	($12,967)
10 Ofs	($7,119)	($626,085)	($67,436)
4 Ofs	($19,703)	($1,889,297)	($197,383)
1 Ofs	($33,685)	($3,307,472)	($341,548)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.3. Energy-related benefits and external costs of CSO control options in the Schuylkill River Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$3,216,685	$4,705,069	$2,171,724
50% LID	$7,813,382	$10,728,581	$4,913,495
75% LID	$10,917,201	$14,950,896	$7,470,850
100% LID	$13,609,791	$18,787,081	$9,441,595
Plant expansion options (excluding LID component)[a]			
157 MGD	($15,316)	($349,321)	($57,000)
747 MGD	($33,322)	($727,346)	($119,692)
1,336 MGD	($49,501)	($988,837)	($172,595)
Tunneling options			
15’ Tunnel	($272,527)	($7,429,041)	($842,353)
20’ Tunnel	($362,014)	($9,537,170)	($1,100,347)
25’ Tunnel	($478,079)	($11,840,716)	($1,394,327)
30’ Tunnel	($621,589)	($14,238,048)	($1,715,633)
35’ Tunnel	($793,412)	($16,506,514)	($2,045,052)
Satellite treatment options			
25 Ofs	($6,648)	($705,765)	($70,845)
10 Ofs	($20,567)	($2,224,732)	($220,716)
4 Ofs	($51,597)	($5,728,678)	($563,893)
1 Ofs	($115,829)	($12,774,988)	($1,256,428)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.4. Energy-related benefits and external costs of CSO control options in the Delaware River Watershed, over 40-year project period (present value, 2009 USD)

	Energy savings (costs)	Air quality health-related improvements (costs)	Carbon footprint reduction (increase)
LID options			
25% LID	$6,713,580	$9,820,003	$4,532,630
50% LID	$16,307,399	$22,391,744	$10,255,012
75% LID	$22,785,416	$31,204,186	$15,592,497
100% LID	$28,405,151	$39,210,732	$19,705,661
Plant expansion options (excluding LID component)[a]			
225/130	($130,530)	($1,259,852)	($179,991)
225/250	($134,230)	($1,690,557)	($207,334)
495/950	($221,295)	($2,439,859)	($278,522)
495/1250	($228,070)	($2,848,114)	($305,397)
Tunneling options			
15’ Tunnel	($408,423)	($9,101,348)	($1,115,480)
18’ Tunnel	($489,540)	($10,503,691)	($1,304,735)
23’ Tunnel	($682,323)	($12,903,993)	($1,670,979)
28’ Tunnel	($929,218)	($15,726,970)	($2,112,658)
31’ Tunnel	($1,089,041)	($17,824,366)	($2,422,831)
Satellite treatment options			
25 Ofs	($8,811)	($438,766)	($49,371)
10 Ofs	($24,959)	($1,167,302)	($133,045)
4 Ofs	($64,856)	($3,331,932)	($367,354)
1 Ofs	($137,147)	($6,784,880)	($750,802)

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.5. Non-monetized energy-related benefits and external costs of CSO control options in the Tacony-Frankford Creek Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			CO_2 emissions (reductions)
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	
LID options						
25% LID	(145.05)	3.41	(38,028,191)	59,440	(35,046,202)	(105,045)
50% LID	(330.20)	(8.24)	(129,277,877)	106,449	(79,771,661)	(235,478)
75% LID	(463.54)	5.56	(183,776,322)	182,578	(111,990,066)	(358,536)
100% LID	(583.72)	16.55	(221,563,669)	247,575	(141,029,264)	(453,597)
Plant expansion options[a]						
215 MGD	6.67	11.19		14,985		2,361
298 MGD	7.29	12.78		17,126		2,666
490 MGD	17.39	21.10		25,277		5,155
820 MGD	24.95	32.03		37,222		7,819
Tunneling options						
15’ Tunnel	133.56	375,913.37		57,002		26,553
20’ Tunnel	176.62	561,135.30		89,378		36,885
25’ Tunnel	225.74	793,910.46		131,335		49,197
30’ Tunnel	283.22	1,082,609.31		184,336		63,986
35’ Tunnel	345.42	1,421,147.25		247,285		80,737
Satellite treatment options						
25 Ofs	3.55	1.75		988		720
10 Ofs	14.57	6.93		4,017		2,868
4 Ofs	63.47	28.51		16,783		12,071
1 Ofs	183.27	80.61		48,179		34,379

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.6. Non-monetized energy-related benefits and external costs of CSO control options in the Cobbs Creek Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			CO_2 emissions (reductions)
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	
LID options						
25% LID	(46.32)	1.09	(12,144,517)	18,983	(11,192,203)	(33,547)
50% LID	(105.45)	(2.63)	(41,285,620)	33,995	(25,475,530)	(75,201)
75% LID	(148.03)	1.78	(58,690,006)	58,307	(35,764,660)	(114,501)
100% LID	(186.42)	5.29	(70,757,609)	79,064	(45,038,492)	(144,859)
Plant expansion options[a]						
63 MGD	12.71	12.26		8,072		3,884
233 MGD	16.93	14.35		8,886		4,775
404 MGD	18.68	15.83		9,115		5,336
Tunneling options						
15' Tunnel	94.69	475,999.78		86,965		24,465
20' Tunnel	126.19	665,540.02		121,974		33,620
25' Tunnel	167.55	962,260.15		178,847		46,873
30' Tunnel	207.52	1,256,965.47		235,991		59,809
35' Tunnel	248.74	1,598,573.93		303,556		74,109
Satellite treatment options						
25 Ofs	3.81	1.65		689		739
10 Ofs	20.74	7.94		3,269		3,761
4 Ofs	62.20	22.23		9,047		10,887
1 Ofs	108.61	37.85		15,467		18,756

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.7. Non-monetized energy-related benefits and external costs of CSO control options in the Schuylkill River Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	CO_2 emissions (reductions)
LID options						
25% LID	(156)	4	(40,843,047)	63,840	(37,640,331)	(112,820)
50% LID	(355)	(9)	(138,847,060)	114,328	(85,676,380)	(252,908)
75% LID	(498)	6	(197,379,493)	196,092	(120,279,600)	(385,075)
100% LID	(627)	18	(237,963,870)	265,900	(151,468,287)	(487,172)
Plant expansion options[a]						
157 MGD	12	11		7,033		3,684
747 MGD	26	24		15,300		7,737
1,336 MGD	35	35		22,729		11,156
Tunneling options						
15' Tunnel	237	742,003		125,136		47,605
20' Tunnel	305	987,092		166,225		62,539
25' Tunnel	379	1,291,300		219,519		79,755
30' Tunnel	456	1,653,470		285,414		98,814
35' Tunnel	528	2,069,410		364,310		118,737
Satellite treatment options						
25 Ofs	23	8		3,053		3,850
10 Ofs	72	23		9,444		11,937
4 Ofs	186	58		23,692		30,399
1 Ofs	415	129		53,185		67,707

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Table G.8. Non-monetized energy-related benefits and external costs of CSO control options in the Delaware River Watershed, over 40-year project period

	Air quality – emissions (reductions)		Energy use (savings)			CO_2 emissions (reductions)
	SO_2 (MT)	NO_x (MT)	Natural gas (kBtu)	Fuel (gallons)	Electricity (kWh)	
LID options						
25% LID	(325)	8	(85,243,992)	133,241	(78,559,566)	(235,468)
50% LID	(740)	(18)	(289,789,289)	238,615	(178,816,154)	(527,847)
75% LID	(1,039)	12	(411,953,001)	409,267	(251,036,931)	(803,695)
100% LID	(1,308)	37	(496,657,118)	554,963	(316,131,196)	(1,016,782)
Plant expansion options[a]						
225/130 MGD	37	49		59,935		11,634
225/250 MGD	49	52		61,634		13,402
495/950 MGD	67	77		101,611		18,003
495/1,250 MGD	78	80		104,722		19,740
Tunneling options						
15’ Tunnel	292	1,089,554		187,535		64,559
18’ Tunnel	337	1,298,714		224,781		75,805
23’ Tunnel	415	1,770,355		313,301		98,203
28’ Tunnel	505	2,363,038		426,667		125,361
31’ Tunnel	572	2,754,184		500,053		144,203
Satellite treatment options						
25 Ofs	14	7		4,046		2,875
10 Ofs	38	19		11,460		7,689
4 Ofs	109	50		29,780		20,947
1 Ofs	222	103		62,973		42,744

a. Plant expansion options are not planned for implementation on their own but will be combined with some level of LID.

Energy savings and emissions offsets: trees. When properly placed, trees can affect energy consumption by shading buildings, providing evaporative cooling, and by blocking winter winds (USDA, 2007). Using data obtained from the USDA, we calculated the energy savings from trees based on average heating and cooling per building. This allowed us to estimate savings in energy costs for the entire community of shaded buildings. We also estimated the reduction in emissions (offsets) associated with these savings.

Energy savings and emissions offsets: green roofs. Green roofs provide insulation and shade for buildings, thus reducing their need for both heating and cooling costs. Using energy savings estimates confirmed by two separate studies, we quantified the energy savings associated with green roofs under each LID CSO control option. To estimate electricity savings (from reduced cooling), we applied an average savings of 0.39 kWh/sq ft of green roof. For natural gas savings (from reduced heating), we used an estimate of 123 MM Btu per building (Doshi, 2005; Green Roofs for Healthy Cities, Undated).

Green sinks – trees. Trees provide a valuable resource for green infrastructure projects by removing (sequestering) CO_2. Trees therefore act as a carbon sink by removing the carbon and storing it as cellulose in their trunk, branches, leaves, and roots while releasing oxygen back into the air. The USDA's UFORE model estimates the CO_2 storage capacity for many species of trees. For our analysis, we used the storage capacity associated with the average-sized tree from the UFORE model as a model for all trees planted under the LID options. We estimated carbon stored simply by multiplying the storage capacity of an average tree according to the USDA by the number of total trees planted.

Green sinks – green roof and bioretention. Green roofs and vegetated bioretention areas also store large amounts of CO_2. The United Kingdom's Department of Environment, Food and Rural Affairs (DEFRA) provides an estimate of sequestered CO_2 per 1,000 square meters (U.K. DEFRA, 2007). Using this rule of thumb, we calculated CO_2 sinks based on the total estimated new green acreage under each LID scenario.

G.3 Summary of Results

Tables G.1 through G.8 show the energy-related benefits and external costs for the different CSO control options in each watershed. Tables G.1 through G.4 show results in physical units (e.g., tons of emissions, energy savings). Tables G.5 through G.8 show the monetary values tied to the physical units in Tables G.1 through G.4. As shown, the largest benefits and costs (in terms of monetary value) under each option can generally be attributed to a reduction of SO_x and NO_x emissions (or net emissions). Under some of the LID options, reductions in NO_x emissions do not completely offset the NO_x emissions associated with energy use (thus, there are positive net emissions).

G.4 Uncertainties and Sensitivity Analysis

G.4.1 Omissions, biases, and uncertainties

To estimate energy savings, costs, and emissions under the different CSO control options, it was necessary to make a number of assumptions. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table G.9 provides a summary of these assumptions and uncertainties and their likely impact on the results of our analysis.

Table G.9. Omissions, biases, and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Estimates of the social cost of carbon are wide ranging and uncertain	+	The IPCC evaluated a range of cost estimates and found an average of $12/MT CO_2. Many recent estimates of the social cost of carbon are found in the upper bound of IPCC's range, including the Stern estimate of $85. Section G.4.2 shows the results of a sensitivity analysis in which a higher social cost of carbon of $48 is used.
Electricity prices are conservative	+	A federal climate policy could increase fossil fuel based energy prices at a much higher rate than the estimates provided in this study. However, an economy-wide policy that would limit GHG emissions is expected, but not a certainty. Section G.4.2 shows the results of a sensitivity analysis in which higher electricity rates are used.
GHG emissions associated with electricity generation in Pennsylvania vary	U	GHG emission factors from power plants vary from plant to plant and from region to region. The actual emissions from the CSO options may be higher or lower than the average emissions factor for the State of Pennsylvania used in this analysis. The emissions factors used in this analysis are the best available option.
Transportation fuel costs	U	An average cost of gasoline and diesel fuel were chosen based on recent prices and adjusted to rise with inflation. It should be noted that fuel prices are volatile and many experts expect fuel prices will rise faster than inflation during the life of this project life. These increases would be expected to be even larger under a federal climate policy. However, technology gains in vehicle efficiency could ease any price increases.
Reduction of energy usage from the planting of trees	-	The blocking of wind in the winter and the shading of buildings during summertime depend on the type of tree planted and the distance and direction from the building. This analysis assumed an estimate of 30% of total trees planted were properly placed to shade during the summer and block wind during the winter. The analysis may be sensitive to this assumption. Benefits would be decreased if 30% is too high.

Table G.9. Omissions, biases, and uncertainties (cont.)

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Carbon sequestration from trees are based on USDA's UFORE analysis of the benefits of Philadelphia's urban forest	U	Different species of trees at different stages of life are able to sequester carbon in varying amounts. This analysis used an average sized tree to calculate total carbon sequestration. A tree growth model was used to simulate the different stages of sequestration as the trees grow over time.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

G.4.2 Sensitivity analysis

We conducted a sensitivity analysis to evaluate the effect of electricity rates and the social cost of carbon on our overall results. This sensitivity analysis compares the benefits and external costs of two CSO control options (50% LID and 30' Tunnel) when a higher social cost of carbon ($48/MT CO_2) versus the IPCC's average ($12/MT CO_2) is used. Our analysis also evaluates the effect on energy savings under the LID options if a doubling in the price of electricity is assumed. Table G.10 shows the results of this analysis.

Table G.10. Sensitivity analysis for city-wide present value benefits of key CSO options: Cumulative through 2049

	50% LID option	30' Tunnel option
Social cost of carbon increase	Total benefits minus external costs	
$12	$2,846.4	$122.0
$48	$2,910.0	$104.3
Percent change in overall results	2.23%	-14.53%
Electricity rate increase resulting from a enacted federal climate policy	Energy savings (usage)	
$0.1 kWh	$2,846.4	$122.0
$0.2 kWh	$2,874.9	$122.0
Percent change in overall results	1.00%	0%

a. Our external cost analysis does not include higher electricity costs associated with the engineering costs for the 30' Tunnel option, but it is assumed that electricity costs would double in this scenario as well. This would be reflected in engineering cost estimates for this option.

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H. Air Quality Pollutant Removal from Added Vegetation

The LID CSO control options currently being evaluated by the PWD would provide (and enhance) recreational amenities within PWD's CSO watersheds. Under the LID options, PWD plans to substantially increase vegetated acreage (including "treed" acreage) throughout the City. Expanding the amount of trees and vegetated acres in Philadelphia will help improve Philadelphia's air quality by removing air pollutants from the atmosphere. Conventional air pollution is a persistent problem for most cities in the United States. Even after decades of concerted federal and state efforts to improve air quality, the majority of the U.S. population lives in areas with ambient air quality above the National Ambient Air Quality Standards (NAAQS). The two air pollutants most damaging to human health are ozone (a gaseous pollutant that is a primary ingredient of smog) and fine particulate matter ($PM_{2.5}$, aerosol particles less than 2.5 microns in diameter, commonly referred to as soot).

The following sections outline Stratus Consulting's methods for estimating the health benefits associated with the improved air quality due to increasing the number of trees that will be planted under the LID options for CSO control. Estimates of total health benefits deriving from trees planted within each watershed are also provided. Additional benefits of air quality relating to avoiding certain air emissions (such as sulfur dioxide and hydrocarbons) related to construction and changes in vehicle traffic are presented in Appendix G.

H.1 Impacts of Trees on Ozone and Particulate Matter

Trees and shrubs have an important effect on reducing important air pollutants including ozone and particulate matter. In addition to other benefits, trees reduce air pollution concentrations. Increased plantings of some tree species (especially trees that naturally emit low levels of biogenic volatile organic compounds) can be a viable component of an air pollution control strategy because trees remove small but significant amounts of ozone and particulate matter from the ambient air. Trees thus can help reduce the air pollution exposure levels of the local population, and help urban areas meet air quality goals.

Ozone (and other gaseous pollutants) are taken into the leaves of trees through stomata respiration. Once inside the leaf, ozone diffuses into intercellular spaces and reacts with inner-leaf surfaces (Nowak et al., 2006). Additional ozone and particulate matter are removed from the ambient air by direct interaction with the leaf surface. Although some particles are absorbed into the leaves, most particles are retained on the surface of the leaf, with 50% assumed to be re-

released to the atmosphere. The remainder is washed off during rain events, or deposited during autumn leaf drop, effectively removing the particulate matter from the air.

A U.S. Forest Service report on the benefits of the Philadelphia urban forests (USDA, 2007) estimates that the existing forest cover in Philadelphia removes 0.33% of the annual mean ozone, and 0.38% of the annual mean particulate matter (PM_{10}), from Philadelphia's air. This removal is from the entire amount of trees and shrubs in Philadelphia. There are an estimated 2.1 million trees covering 15.7% of the land area of Philadelphia; an additional 5.9% of the land area is covered by shrubs.

These Forest Service estimates of the impact of Philadelphia's trees are used as the basis for the air pollution-related health analysis, and the subsequent economic benefit analysis, reported in this appendix. This analysis assumes that $PM_{2.5}$ is reduced by the same proportion (0.38%) as total respirable particulate matter (PM_{10}), and calculates the avoidable health effects from reducing $PM_{2.5}$ levels.

H.2 Philadelphia Air Quality Situation

Like most major cities in the United States, EPA currently classifies Philadelphia County (and the entire greater Philadelphia metropolitan area) as exceeding the current NAAQS for both ozone and $PM_{2.5}$. Recent ozone levels[1] in Philadelphia exceed the current ozone standard by 19%. Philadelphia County's $PM_{2.5}$ levels are below the national fine particle standards (maximum 2008 monitor value in Philadelphia County had an annual mean of 13.49 $\mu g/m^3$, compared with the NAAQS of 15.0 $\mu g/m^3$), although higher $PM_{2.5}$ levels in adjoining counties result in the Philadelphia metropolitan area being classified as a $PM_{2.5}$ non-attainment area. As a designated non-attainment area, Philadelphia must develop and periodically update their State Implementation Plan, identifying additional control measures that will allow Philadelphia to achieve attainment by 2015, and maintain the level of the standards thereafter.

Air pollution levels in Philadelphia vary year to year, reflecting variability both in meteorology and economic activity. Non-attainment designations are based on three years of monitoring data to accommodate the year-to-year variability. Philadelphia's air quality has been generally getting better over time, as numerous federal, state, and local emission control requirements take effect.

This analysis of the air pollution impacts of increasing the number of trees in Philadelphia County uses monitor data from 2007 (the most recent complete year at the time of the analysis). In 2007, the highest monitor in Philadelphia County had a second highest 8-hour ozone level (the

1. The three-year (2006–2008) ozone fourth highest maximum for eight hour ozone in Philadelphia County is 89 ppb. The 2008 revision to the ozone NAAQS set the standard (as measured by the same metric) at 75 ppb.

averaging time of the NAAQS) of 110 parts per billion (ppb); the lowest monitor was 87 ppb (all exceeding the NAAQS). The 2007 annual mean $PM_{2.5}$ levels at the highest monitor in Philadelphia County was 14.83 $\mu g/m^3$ (below the standard of 15.0 and the lowest monitor was 12.77).

The initial air pollution levels in this analysis are derived from the 2007 ozone and $PM_{2.5}$ air quality monitors in Philadelphia County. In this analysis the county-wide population-weighted average annual average $PM_{2.5}$ level is 13.60 $\mu g/m^3$. The county-wide population-weighted seven month (April through October) seasonal average of the daily 8-hour maximum ozone is 42.4 ppm. Changes in the seasonal average of ozone are the determinates of ozone's impact on human health, rather than changes in peak daily values used to determine attainment of the ozone NAAQS.

As described above, increasing the size of the urban forest in Philadelphia County is expected to lower the ambient ozone and $PM_{2.5}$ concentrations. Using the relationship from the Forest Service report (USDA, 2007) that the current 2.1 million tree urban forest reduces ozone by 0.33% and $PM_{2.5}$ by 0.38%, an increase in the number of trees planted in the 50% LID option[2] would reduce recent (2007) ozone levels by 0.04 ppb, and $PM_{2.5}$ by 0.02 $\mu g/m^3$ when the trees are fully mature. The benefits analysis assumes that future ozone and $PM_{2.5}$ levels will be reduced by the same amount (for the same number of planted trees). Varying the number of trees planted, such as in other LID options, is assumed to proportionally effect the changes in ozone and $PM_{2.5}$ levels.

H.3 Human Health Effects of Ozone and $PM_{2.5}$ Exposure

The adverse health effects of ozone and $PM_{2.5}$ are well established, and are extensively documented in recent EPA documents such as EPA's Regulatory Impact Analysis (RIA) for the 2008 revisions to the ozone NAAQS (U.S. EPA, 2008b). Adverse human health effects that can be avoided by reducing ambient levels of ozone and $PM_{2.5}$ include premature mortality and a broad array of respiratory and cardiovascular health effects. Health effects occur not only above the level of the NAAQS, but also below the level of the standards.

The avoidable air pollution-related health effects estimated in this analysis are:

- Premature mortality (from ozone and $PM_{2.5}$)
- Onset of irreversible chronic bronchitis ($PM_{2.5}$)

2. The 50% LID option includes planting 637,000 trees if implemented in all four watersheds, or an increase of 30% in the total number of trees in Philadelphia County.

- Heart attacks (non-fatal acute myocardial infarctions) ($PM_{2.5}$)
- Hospital admissions (non-fatal) for respiratory and cardiovascular conditions (from ozone and $PM_{2.5}$)
- Emergency room visits for asthma (from ozone and $PM_{2.5}$)
- Respiratory symptoms (days of illness) (from ozone and $PM_{2.5}$)
- Work loss days ($PM_{2.5}$) and school absence (ozone).

This analysis uses software developed by the EPA to calculate the avoided health effects from the contribution of trees to reducing ozone and $PM_{2.5}$ concentrations, and to estimate the economic value of the avoided health effects. EPA's BenMAP (U.S. EPA, 2008a), the Environmental Benefits Mapping and Analysis Program (Ver. 3.0.15), was used to conduct this analysis.

H.4 Methods of Estimating Health Effects of Improvements in Air Pollution from an Increase in the Number of Trees

The fundamental method used in this analysis is to calculate the avoided health effects associated with "rolling-back" the air quality levels recorded by Philadelphia monitors in 2007 by the Forest Service's estimate of the percentage that trees reduce air pollution. As a first step in the analysis, BenMAP estimated the health effects associated with reducing 2007 monitor levels of both ozone and $PM_{2.5}$ by 1%. These estimated health effects are proportionally adjusted to estimate the health effects associated with the specific estimated air pollution changes resulting from increasing the amount of urban forest in Philadelphia by the amounts associated with tree planting in each of the LID options.

The BenMAP closest monitor algorithm was used to estimate the population-weighted average change in ozone and $PM_{2.5}$ by assigning the population in Philadelphia (BenMAP forecast for 2010 = 1,438,198, based on 2000 tract level Census data and EPA forecasts of county-level population changes) to the closest monitor to their point of residence. There are four EPA monitors in Philadelphia County; all four monitors record ozone and $PM_{2.5}$ levels.

The health effects analysis methods are adopted from the methods used by EPA in the 2008 ozone NAAQS RIA (U.S. EPA, 2008b). BenMAP was used to estimate the avoided health effects using a concentration-response function from each of the individual concentration-response functions that EPA used in the 2008 ozone NAAQS RIA.

Because the benefits calculations are dominated by premature mortality associated with $PM_{2.5}$, the benefit estimates are made using two different estimates of $PM_{2.5}$-related adult premature mortality. This use of two estimates creates a high estimate and a low estimate for the benefits. The high estimate is from a concentration-response function derived from a long-term cohort tracking epidemiology study in six eastern U.S. cities (Laden et al., 2006). The low estimate is from a long-term cohort tracking epidemiology study of 50 cities nationwide (Pope et al., 2002).

The health analysis estimates the annual cases in Philadelphia of each category of avoided health effects associated with implanting each of the four LID options. Table H.1 presents a representative result; the numbers of avoided cases for implementing the 50% LID option in all four watersheds (e.g., the health benefits of planting 637,000 trees, when the trees reach mature size).

Table H.1. Avoided cases in Philadelphia County for the 50% LID option implemented in all four watersheds (assuming 2010 population)

Health effect	Avoided cases
Premature mortality	1.0 deaths/year (low estimate from Pope et al., 2002)
	2.4 deaths/year (high estimate from Laden et al., 2006)
New cases of chronic bronchitis	0.4 cases/year
Heart attacks	1.2 cases/year
Hospital admissions (all types)	1.0 cases/year
Asthma attacks	23 cases/year
Respiratory illness days	708 days of illness/year
Work loss days and school absence	250 days/year

Varying the number of trees planted, such as in other LID options, is assumed to proportionally effect the health benefits of the changes in ozone and $PM_{2.5}$ levels.

H.5 Economic Valuation of the Avoided Health Effects

In order to include the air quality-related health effects in a benefit-cost analysis containing other benefit categories (energy savings, cooling effects, etc.), it is useful to estimate the economic value of the health effects. For purposes of air pollution policy analysis, the EPA estimates the value of avoiding a case of each estimated health effect, and these estimates (expressed in terms of 2006 prices and forecasted 2010 income levels) are used in this analysis. The EPA valuation estimates are included in the BenMAP software (U.S. EPA, 2008a), which was used to conduct both the health and valuation analyses.

According to economic theory, the best measure of the value of reducing the risk of an adverse health effect is the average that individuals are WTP to reduce the risk a small amount. EPA's methods for valuing air pollution health effects use WTP valuation measures wherever possible, relying on periodic EPA reviews of existing economic studies. However, for certain endpoints reliable WTP studies are not available. EPA has developed alternative methods for valuing the health effects without WTP valuations. The alternative methods produce a lower value estimate than a WTP method because they only consider a portion of the total demand (WTP) for avoiding a health risk. For example, hospital admissions are valued using the medical costs incurred during the stay in the hospital; this ignores the pain and suffering components of value that would be included in WTP. Heart attacks are valued using a combination of medical cost information plus the lost stream of income from people not able to re-enter the workforce (or who must work at a reduced level of income) after a heart attack. The heart attack valuation thus also ignores the pain and suffering components of WTP, and does not include lost income for people assumed to be out of the workforce (e.g., retirees and unemployed adults).

Background and detailed sources of all values used in this analysis are available in the BenMAP documentation and technical appendices (U.S. EPA, 2008a). The values for each health effect are presented in Table H.2.

Table H.2. Values for one case of each health effect

Health effect	Value per case (2006 prices, 2010 income)
Premature mortality	$7,000,000
Chronic bronchitis	$196,000
Heart attack	$141,000 to $233,000 (varies by age)
Hospital admission	$15,000 to $33,000 (varies by cause of hospitalization and age)
Emergency room visit	$336
Asthma attack	$189
Illness day	$18 to $59 (varies by illness)
Work loss days	$143
School absence	$89

Using the methods described above, the total annual health value implementing the 50% LID option in all four watersheds (an increase of 30% in the number of trees in Philadelphia County) is between $12.5 million (based on the low estimate of $PM_{2.5}$ adult mortality from Pope et al., 2002) and $20.5 million (with the high estimate of $PM_{2.5}$ adult mortality from Laden et al., 2006). The corresponding annual benefits per tree planted are between $19 (low estimate) and $45 (high estimate). The mean per tree annual benefit is $32. Varying the number of trees

planted, such as in other LID options, is assumed to proportionally affect the total health benefits of the changes in ozone and $PM_{2.5}$ levels, but the benefit per tree will remain constant.

As described in the following sections however, these benefit estimates are not realized immediately when a tree is planted. The schedule in planting trees, plus the time required for a tree to grow to maturity, significantly reduce the present value of planting each tree due to discounting of the value of the avoided health effects.

H.6 Estimates of Trees Planted, the Timeline for Planting Trees, and Time to Reach Maturity

The number of trees planted under each LID option in each of the four watersheds are presented in Table H.3.

Table H.3. Number of trees planted in each watershed under the LID options

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware
25% LID	38,612	12,331	41,470	86,553
50% LID	137,537	43,923	147,718	308,304
75% LID	195,743	62,511	210,231	438,776
100% LID	235,032	75,059	252,429	526,848

There are two assumptions about trees that influence the benefits estimation: the schedule for tree planting, and the time it takes for trees to grow to maturity. Both of these factors result in the full air quality health benefits of the increased number of trees being realized well after the LID program activities begin.

The timeline of program activities provided by CDM shows the total number of trees planted in each LID option will be planted over a 35-year period. Approximately 10% of the trees will be planted over the first 6 years of the planting program, 35% planted over the following 14 years, and 55% planted over the final 15 years. Planting begins in 2010, and is not completed until 2045.

When initially planted trees are not fully mature, and cannot produce the full air quality improvement benefits immediately. For the purpose of this analysis, each newly planted tree is assumed to take 20 years to reach maturity in terms of improving air quality. Newly planted trees are assumed to grow at a uniform rate (in air quality removal terms) throughout the 20-year growth period. After the 20-year growth period, the air quality improving characteristics of a

planted tree are assumed to remain constant, with urban forestry management practices replacing the trees as necessary to maintain the same effective level of air pollution improvements.

The combination of the 35 year planting schedule and the 20-year tree growth assumption results in the full benefits of air quality improvements for an LID option not being realized until 55 years after the planting begins. The effect of the time delays in the planted trees reaching their full effect on air quality and human health is reflected in the benefit cost analysis through discounting the value of the health effects from the year the health effects are realized back to the time the LID program begins. The discount rate (4.875%) and project initiation year (2008) are the same as used in all portions of the benefits analysis.

H.7 Estimated Economic Benefits

Table H.4 presents a summary of the present value of the health related benefits deriving from air quality improvements resulting from the trees planted in each LID option.

Table H.4. Present value of air quality-related health benefits from tree planting under the LID options (USD millions)

	Tacony-Frankford	Cobbs Creek	Schuylkill	Delaware	Total
25% LID	$7.9	$2.5	$8.5	$17.8	$36.8
50% LID	$28.3	$9.0	$30.4	$63.4	$131.0
75% LID	$40.2	$12.8	$43.2	$90.2	$186.5
100% LID	$48.3	$15.4	$51.9	$108.3	$223.9

H.8 Omissions, Biases, and Uncertainties

To estimate the health benefits from air quality improvements associated with planting trees under the LID alternatives, it was necessary to make a number of assumptions in the absence of specific data. In addition, a number of data omissions and uncertainties surrounding the analysis have been identified throughout this report. Table H.5 provides a summary of these assumptions and uncertainties and their likely impact on our estimation of our air quality related health benefits from tree planting.

Table H.5. Omissions, biases, and uncertainties

Assumption/methodology	Likely impact on net benefits	Comment/explanation
Air quality improvements are based on the Forest Service analysis of the air quality benefits of the existing Philadelphia urban forest	U	The ozone and $PM_{2.5}$ improvements from increasing the number of trees in Philadelphia's urban forest is projected to increase proportionally as the size of the urban forest is increased. Changes in species composition of the planted trees may make the relationship nonlinear, making the impact on benefits uncertain.
Non-Philadelphia residents are not included in the analysis	+	Planting trees in Philadelphia County will likely improve air quality in adjoining counties as well. Air quality improvements in the densely populated adjoining locations are not included in the analysis, and would increase the benefits.
Trees are assumed to decrease $PM_{2.5}$ the same amount that the USDA UFORE analysis estimated PM_{10} is reduced by the existing Philadelphia urban forest	--	$PM_{2.5}$ is more toxic than an equal amount of PM_{10}. If trees are less effective at reducing $PM_{2.5}$ concentrations than in reducing PM_{10}, the tree planting will result in smaller $PM_{2.5}$ changes than estimated in this report. $PM_{2.5}$ contributes more to the total benefit value than ozone, so a smaller change in $PM_{2.5}$ levels would reduce benefits more than a comparable degree of change in ozone.
Trees are assumed to have the same reductions in ozone and PM levels in the future as they do now	-	Over the past several decades air quality levels in Philadelphia have been improving steadily since air pollution programs began to substantially reduce emissions. This trend will generally continue as older cars are retired, additional control programs are implemented, etc. If air quality is cleaner in the future, the impact of additional trees could be less, resulting in smaller improvements in $PM_{2.5}$ and ozone levels than modeled here.

+ would increase benefits; ++ would increase net benefits significantly; U uncertain direction of change; - would diminish net benefits; -- would diminish net benefits significantly

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I. Construction- and Maintenance-Related Disruption Impacts

Under all of the CSO options, construction activities will likely result in occasional delays and increased travel times for passenger and commercial vehicle travelers in Philadelphia. Travel time delays can be caused by:

- General traffic slowdowns associated with an increase in the number of trucks and construction equipment on the road
- Slowdowns from trucks entering and exiting construction or landscaping sites
- Lane or road closures associated with construction in the roadway or road right-of-way.

In addition to the value of "lost" time spent in traffic, construction-related delays can result in increased costs associated with additional fuel used by vehicles as a result of slower speeds and occasional vehicle stops and idling.

The following sections outline Stratus Consulting's approach for estimating the costs associated with travel time delay and additional fuel used under the different CSO options. Cost estimates associated with construction-related delays are also provided.

I.1 Impact of Additional Construction and Maintenance Vehicles on Philadelphia Roadways

To estimate travel time delay caused by an increase in the number of construction and maintenance vehicles on Philadelphia's roadways, we first estimated the number of miles traveled by these vehicles under the different CSO alternatives. We calculated total VMT based on inputs received from CDM, including the number of heavy truck trips over the construction period and total person-hours of O&M labor per year. We made several assumptions regarding average trip length per vehicle, number of concrete trucks under the non-LID alternatives, and the average number of employees per truck (crew size) for O&M vehicles.

Table I.1 shows the inputs and assumptions used to determine additional truck miles traveled under the different CSO options.

Table I.1. Inputs and assumptions for estimating additional VMT under CSO options

	LID alternatives
Heavy truck trips	
Vehicle trips (heavy trucks/construction)	Provided by CDM for each alternative
Vehicle trips (concrete trucks)	For non-LID alternatives, assumed to equal ½ of heavy vehicle construction trips
Average trip length (miles)	20
Light truck trips (LID options only)	
Person-hours of O&M labor per year	Provided by CDM for each LID alternative
Working hours per year	2,000
Persons per truck (crew size)	4
Number of additional trucks on the road each day	Number of employees divided by crew size
Average trip length (miles)	15

Using the total VMT by construction and maintenance vehicles under each option, we were able to estimate the travel time delay caused by these vehicles based on methodology developed by the Texas Transportation Institute (TTI) (Schrank and Lomax, 2007). The following sections outline our general approach and provide monetary and non-monetary cost estimates for construction-related impacts under each of the CSO alternatives. Non-monetary estimates are presented in terms of total hours of delay.

Step 1: Determine congested peak period VMT. This first step is based on the assumption that an increase in the number of construction vehicles on Philadelphia's roadways will only affect vehicles already traveling in congested conditions. Thus, vehicles traveling in uncongested conditions would continue to travel at "free-flow" speeds despite the addition of extra vehicles. We assume that congestion is typically only experienced during certain times of the day (i.e., during "peak" periods).

Based on the TTI's Annual Mobility Report (Schrank and Lomax, 2007), peak period travel accounts for 50% of DVMT. Further, TTI estimates that in Philadelphia, 63% of peak period travel is spent in congested conditions. Thus, approximately 32% (50% $\times$ 63%) of DVMT is considered to be congested, peak period travel.

Step 2: Determine VMT impacted. Only a small percentage of congested peak period travel will experience traffic delays or slow downs due to an increase in the number of trucks on the road. To determine total VMT affected, we assume that for each heavy construction vehicle mile traveled, an additional 30 vehicle miles (or 30 vehicles) are impacted. Thus, if 10 million vehicle miles are traveled under a given CSO option, we assume that 300 million passenger and/or

commercial vehicle miles are traveled at slower speeds. In the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude of costs.

Step 3: Estimate impact on traffic speed. We assume construction vehicle travel to be consistent with current traffic patterns, with approximately 42% of travel taking place on highways and 58% on arterial roads (Schrank and Lomax, 2007). TTI reports that during peak periods, the average highway speed in Philadelphia is about 45.6 miles per hour (mph). On arterial roads, the average speed is approximately 27.5 mph. We estimate that the speed of affected vehicles will decrease by approximately 8 and 10% on highways and arterial roads, respectively (to 42 and 24.8 mph). Again, in the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude for potential impacts.

Step 4: Estimate travel time and determine annual delay. The fourth step involves calculating the amount of time it would take to travel the affected vehicle miles at decreased speeds and at current (or baseline) speeds. This calculation yields travel time on an hourly basis and was performed separately for arterials and freeways under each scenario. Total annual vehicle *delay* was then determined by comparing travel time under decreased speeds for each alternative to travel times at current speeds.

To determine total person delay, we distinguish between heavy truck travel and passenger vehicle travel. Based on TTI data, we assume that 5% of total travel can be attributed to heavy trucks and that these vehicles typically have only one passenger (the truck driver). Passenger vehicles are assumed to contain an average of 1.25 passengers per vehicle, including the driver (Schrank and Lomax, 2007).

Based on the steps described above, we were able to estimate travel time delay caused by construction and implementation activities under each CSO option. Our estimates reflect total delay over the 40-year project period. To estimate annual delay over the project life, we allocated total delay based on construction and implementation timelines provided by CDM.

Table I.2 provides total person-delay estimates (accounting for 1.25 persons per passenger vehicle) for the CSO options in each watershed.

Table I.2. Total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (person-hours)

	Tacony	Cobbs	Schuylkill	Delaware
LID options				
25% LID	41,801	13,349	44,895	93,701
50% LID	74,840	23,901	80,380	167,762
75% LID	128,378	40,998	137,881	287,772
100% LID	174,087	55,596	186,973	390,233

Table I.2. Total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (person-hours) (cont.)

	Tacony	Cobbs	Schuylkill	Delaware
Transmission and new treatment capacity (excluding LID component)[a]				
Level 1	10,541	5,678	4,947	42,162
Level 2	12,048	6,251	10,763	43,357
Level 3	17,781	6,412	15,989	71,479
Level 4	26,184			73,667
Tunnel options[b]				
15' Tunnel	40,098	61,176	88,027	131,922
20' Tunnel	62,873	85,803	116,932	158,123
25' Tunnel	92,388	125,811	154,421	220,393
30' Tunnel	129,672	166,009	200,775	300,141
35' Tunnel	173,954	213,537	256,275	351,764
Transmission and satellite treatment options				
25 Ofs	695	485	2,147	2,846
10 Ofs	2,826	2,299	6,643	8,062
4 Ofs	11,806	6,364	16,666	20,949
1 Ofs	33,892	10,880	37,413	44,299

a. Levels 1–4 correspond to the different capacity options within each watershed (e.g., for Tacony-Frankford Watershed, Levels 1–4 are 215, 298, 490, and 820 MGD, respectively.

b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28 and 31'.

I.2 Wasted Fuel

To calculate wasted fuel due to vehicles moving at slower speeds, we again draw upon methodology developed by TTI. We first calculate average fuel economy based on a linear regression applied to a modified version of fuel consumption reported by Raus (1981), as follows:

$$\text{Average fuel economy} = 8.8 + 0.25\ (\text{average speed})$$

This equation is applied to average speeds for arterials and freeways. Annual fuel consumed as a result of the delay under each CSO option is then calculated:

$$\text{Annual fuel consumed} = \text{Travel delay (vehicle hours)} \times \text{Average speed} / \text{Average fuel economy}$$

The additional fuel use associated with construction-related delay is reported under the "energy usage/savings" category for each CSO alternative (Appendix G). The value of this "wasted" fuel is also reported as part of this category (in terms of total energy costs). However, we can provide an idea of total costs associated with additional fuel used as a result of construction-related delay. At $3.00 per gallon, additional fuel use amounts to about 16% of the total costs estimated for travel time delay, which is reported below.

I.3 The Value of Travel Time Delay Caused by Additional Construction Vehicles on the Roadways

To determine the value of extra time spent in traffic, we applied hourly rates used by the U.S. Department of Transportation and TTI to value an individual's time. Hourly rates for passenger vehicle travelers are weighted by a standard to account for both leisure and work-related travel (approximately $16.00 per hour). Heavy truck travel (assumed to be commercial truck travel) represents hourly wage plus fringe benefits (approximately $84 per hour). These values are based on 2005 TTI estimates and inflated by 3% to reflect 2008 values.

Table I.3 shows the total value of travel time delay caused by additional vehicles on Philadelphia roadways. The values shown here represent present value estimates for the 40-year project timeline. Similar to hours of delay, these costs were allocated by year based on construction and implementation timelines provided by CDM.

Table I.3. Monetary value of total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (present value, 2009 USD)

	Tacony	Cobbs	Schuylkill	Delaware
LID options				
25% LID	$677,244	$216,282	$727,374	$1,518,111
50% LID	$1,210,066	$386,441	$1,299,636	$2,712,484
75% LID	$2,077,509	$663,464	$2,231,286	$4,656,943
100% LID	$2,818,088	$899,972	$3,026,684	$6,317,026
Transmission and new treatment capacity (excluding LID component)[a]				
Level 1	$177,872	$95,815	$83,479	$711,433
Level 2	$203,292	$105,483	$181,616	$731,600
Level 3	$300,043	$108,195	$269,800	$1,206,134
Level 4	$441,823	NA	NA	$1,243,061

Table I.3. Monetary value of total vehicle delay caused by additional construction and maintenance vehicles on Philadelphia roadways under PWD's CSO options (present value, 2009 USD) (cont.)

	Tacony	Cobbs	Schuylkill	Delaware
Tunnel options[b]				
15' Tunnel	$676,617	$1,032,283	$1,485,367	$2,226,049
20' Tunnel	$1,060,923	$1,447,835	$1,973,102	$2,668,168
25' Tunnel	$1,558,954	$2,122,931	$2,605,699	$3,718,904
30' Tunnel	$2,188,081	$2,801,233	$3,387,882	$5,064,569
35' Tunnel	$2,935,292	$3,603,223	$4,324,377	$5,935,660
Transmission and satellite treatment options				
25 Ofs	$11,731	$8,177	$36,234	$48,025
10 Ofs	$47,680	$38,799	$112,099	$136,036
4 Ofs	$199,213	$107,387	$281,222	$353,488
1 Ofs	$571,892	$183,593	$631,312	$747,498

a. Levels 1–4 correspond to the different capacity options within each watershed (e.g., for Tacony-Frankford Watershed, Levels 1–4 are 215, 298, 490, and 820 MGD, respectively.
b. Tunnel options in Delaware River Watershed are 15, 18, 21, 23, 28, and 31'.

I.4 Delay Associated with Temporary Lane/Road Closures

To estimate annual vehicle delay associated with detours and temporary lane and/or road closures, we would ideally know the location and duration of each closure as well as the number of travelers affected and their speed over the impacted area. Because we are uncertain of how these variables might vary under each alternative, we do not include the impact of lane and road closures in our overall analysis.

In the absence of this detailed information, we can provide a rough benchmark estimate of annual delay caused by construction activities in the roadway based on the following assumptions:

- Five percent of travelers are impacted
- Each affected traveler experiences an average of a 5-minute delay per lane/road closure and/or detour
- Affected travelers experience the delay twice a day, an average 250 days each year (total working days in a year)

- Vehicles will experience these delays on arterial streets as opposed to freeways
- Travelers can experience delays throughout the day (not just during peak periods)
- Heavy trucks account for approximately 5% of total traffic and typically contain only one person (the driver)
- Passenger vehicles have an average of 1.25 persons per vehicle.

Based on these assumptions, we estimate that increased construction activities under the different CSO options could delay Philadelphia truck drivers and passenger vehicle occupants by an additional 12,200 hours each year (about 15,100 person-hours). If this is assumed to be the average impact each year over the 40-year project, total vehicle delay would amount to about 490,000 hours.

The key variables here are the percent of travelers affected and the amount of time and frequency that each vehicle is delayed. Again, it is uncertain how these variables might vary across the different options. The assumptions described above are intended to provide a benchmark estimate from which to gauge potential impacts.

Table I.4 shows the inputs and the order-of-magnitude estimate associated with this city-wide impact.

Table I.4. Inputs and preliminary estimates for total delay caused by lane closures and/or detours

	Input/preliminary estimate
Daily vehicle-miles of travel (1,000s) on arterial roads	48,235
Arterial road lane miles	8,240
Total number of vehicles on arterial roads per day	5,850
Percent of total travelers affected	5%
Total travelers affected	290
Daily hours of delay	49
Number of days delay is experienced	250
Annual hours of vehicle delay	12,200
Annual hours of delay for heavy trucks	610
Annual hours of passenger vehicle person-delay	14,480
Total annual hours of person delay	15,100

This estimate will vary each year depending on the level of activity in any given year. In the absence of this information, it is difficult to estimate the present value of this benefit. Further, due to lack of more detailed information, we were unable to calculate the cost of wasted fuel due to idling and slower speeds associated with this type of delay.

I.5 Other Non-quantifiable Impacts

I.5.1 Neighborhood and business access issues

In some cases, access to residential areas and local businesses may be made difficult by construction and maintenance activities. In residential areas, access issues can result in increased travel time for residents having to choose alternate routes in traveling to and from their homes. Employees and customers of local businesses may also experience increased travel times from having to choose alternate routes or visit other businesses. Some local businesses may temporarily see a decline in the number of customers visiting their businesses.

I.5.2 Temporary construction impacts

Other public impacts from construction and maintenance can include mitigation or repair of construction-related damage due to tunneling settlement and vibration or equipment damage to private property. Additional impacts may include noise, dust, vibration, and safety issues associated with construction activities. These impacts are typically experienced by residents and businesses within the project area, including those located on streets where detours have been routed. These miscellaneous other social costs will not likely represent a large portion of overall project costs and in the absence of specific data, they are described qualitatively.

I.6 Omissions, Biases, and Uncertainties

As detailed throughout this report, to estimate traffic-related impacts associated with the different CSO control options, it was necessary to make a number of assumptions. Many of these assumptions are based on Philadelphia-specific data (average speeds, annual VMT, etc.) or represent standard industry estimates (e.g., number of person per vehicle, wage rates). Although there is a degree of uncertainty surrounding these assumptions, they are developed based on well-accepted methodology (see Schranx and Lomax, 2007) that has been used to evaluate mobility and traffic patterns in urban areas for a number of years.

Additional uncertainties surrounding our analysis of construction-related costs generally stem from a lack of specific data related to on-the-ground implementation of the CSO options (location, expected road closures, etc.). Table I.5 provides a summary of these assumptions and uncertainties and their likely impact on total benefits.

Table I.5. Omissions, biases and uncertainties

Assumption/ methodology	Likely impact on net benefits[a]	Comment/explanation
Analysis does not include the impact of temporary lane and/or road closures during construction.	++	Depending on their timing and location, temporary lane and road closures could significantly increase the overall costs associated with construction disruption, in terms of additional time spent in traffic and wasted fuel. Further, individual businesses could experience significant impacts if they are located on a closed road. This would not likely result in substantial impacts on a city-wide basis (e.g., residents would continue to shop, just in different locations).
Analysis assumes miles traveled by additional construction vehicles on highways versus arterial roads, follows current traffic patterns.	U	It is unclear how this assumption affects our current estimates. If construction vehicles spend more time driving on arterial roads, impacts would be greater because we assume a larger impact on arterial roads for each vehicle. (e.g., we estimate that the speed of affected vehicles will decrease by approximately 8 and 10% on highways and arterial roads, respectively)
Analysis includes assumption for VMT impacted by additional construction vehicles.	U	To determine total VMT affected, we assume that for each heavy construction vehicle mile traveled, an additional 30 vehicle miles (or 30 vehicles) are impacted. In the absence of specific roadway data, this assumption is intended to serve as a benchmark to provide an order of magnitude of costs.

a. Indicating how addressing the assumption or overcoming the omission would probably impact the analysis, using the following key: + would likely increase net benefits; ++ would increase net benefits significantly; U direction of change in net benefit is uncertain; - would diminish net benefits; -- would diminish net benefits significantly.

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