Office of Brownfields and Land Revitalization

Air and Water Quality Impacts of Brownfields Redevelopment

A Study of Five Communities

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U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Brownfields and Land Revitalization
Washington, DC 20460
April 2011

EPA 560-F-10-232

Acknowledgments

This document was prepared for the U.S. Environmental Protection Agency's Office of Brownfields and Land Revitalization (OBLR). The project management team consisted of Stacy Swartwood of OBLR and John V. Thomas of the EPA's Office of Sustainable Communities.

This report would not have been possible without the assistance of staff throughout U.S. EPA, and a number of officials and staff at state, county, and local jurisdictions, including Baltimore Development Corporation, Baltimore Metropolitan Council, City of Dallas Brownfields Program, City of Emeryville Redevelopment Agency, City of Minneapolis Assessor's Office, City of Saint Paul Property Information Office, Environmental Coalition of South Seattle (ECOSS), Fort Worth environmental Management Department, Hennepin County Dept of Environmental Services, King County department of Natural Resources, Maryland Department of Assessments, Maryland Department of the Environment, Metropolitan Transportation Commission (California) (MTC), Minneapolis Environmental Initiative, North Central Texas Council of Governments (NCTCOG), Puget Sound Regional Council (PSRC), Saint Paul Port Authority, Purdue University Agricultural and Biological Engineering Department, Seattle Department of Planning and Development, Twin Cities Metropolitan Council, and U.S. EPA Brownfields teams in Regions 3, 5, 6, 9, and 10.

Table of Contents

Page

1. Introduction and Summary

1.1 Introduction

A number of previous studies have compared the environmental performance of specific brownfield redevelopments with similar projects built on undeveloped greenfield sites, which often are located in less dense and less accessible areas.[1] These studies generally examined a single brownfield or infill development and entailed extensive site-specific analysis. The comparison greenfields generally accommodated the same number of residential units and commercial square footage, but their designs typically used more acreage per employee or per residence and were less location efficient. A review of 12 of these studies concluded that the brownfield and infill developments result in significant environmental benefits compared to their greenfield counterparts (Appendix A). However, making broader quantitative assessments of other brownfield redevelopment around the country requires a methodology that is more easily transferable.

This study tests an analytical approach to quantifying the environmental impacts of multiple redevelopment projects in a given municipal area in a manner that can be replicated in other regions. The method was applied to five cities and their surrounding areas—Seattle, Washington; Baltimore, Maryland; Minneapolis-Saint Paul, Minnesota; Emeryville, California; and Dallas-Fort Worth, Texas. These municipal areas correspond approximately to metropolitan statistical areas as defined by the U.S. Census Bureau.

1.2 Study Approach

The municipal areas were selected based on several factors, including a significant number of brownfield properties that had benefited from assistance from U.S. EPA's Brownfields Program and had development completed or under way, the availability of information about the reuse status of the brownfield sites, and the availability of data that could be used as indicators of local environmental performance. Most of these properties are in close-in, highly developed areas.

Alternative development locations were identified for each of the brownfield sites, based on prevailing development trends in the area. Most, but not all of the alternative sites were located outside the urban core. That is, it was assumed that had the brownfields been unavailable, the development would have gone to these locations. Development on suburban and exurban sites consumes more acreage per resident or employee than urban core project areas. It was assumed that these projects were sited on greenfields and would require 2-4 times the acreage typically used for development on brownfield sites. This assumption, believed to be conservative, is derived from factors drawn from literature on land use patterns by type of use as well as experience in the Puget Sound area. Nearly all alternative locations identified for this study would require more land to accommodate the same type of development on brownfield sites.

The environmental performance of both sets of locations was measured and compared in terms such as vehicle use per capita, air pollutant emissions per capita, personal vehicle energy use per capita, and stormwater runoff and pollutant loads. The environmental performance measures were developed with data from regional transportation demand models, a watershed management model, and INDEX, a geographical information system-based analytical tool (EPA 2001b, Allen 2008). Appendix B contains a more detailed description of the methodology.

[1] EPA defines "brownfield site" as real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant.

A total of 163 brownfield properties met the criteria for inclusion in the study. These properties represent 35-40% of the total number identified in EPA's ACRES database for the five cities. The other sites were not included in the study either because they had not been redeveloped, or because confirmation that the property had benefited from U.S. EPA Brownfields Program assistance was not available. In a few cases, sites were not included because it was difficult to categorize their use for the purposes of this study, such as a property that was used for a bridge approach. The 163 developed brownfield sites account for a relatively small portion of total development acreage in these areas, however, their reuse has been important to the communities in overcoming obstacles to redevelopment. Exhibit 1-1 provides summary information for the five municipal areas.

Exhibit 1-1. Municipal Areas Included in Study

City	No. of Brownfield Properties [(a)]	Brownfield Acreage	City Population in Thousands (Year)	City area (Sq. Mi.)	Planning Area	Population in Planning Area (millions)
Seattle	25	87	592.8 (2007)	83.87	4-county area	3.6
Minneapolis-Saint Paul	37	80	676.7 (2007)	114.60	7-county area	2.9
Emeryville	39	183	10.1 (2009)	1.9	9-county area	5.1
Baltimore	37	322	636.9 (2008)	92.07	5 counties & Baltimore City	2.5
Dallas-Ft. Worth	25	266	2,026.6 (2009)	678	12-county area	6.5
Total	163	938				

(a) Properties that have received EPA Brownfields Program assistance and have been, or are being, redeveloped.

1.3 Results

Indicators of environmental performance, such as carbon dioxide (CO_2) emissions, personal vehicle energy use, and stormwater runoff, were estimated for each of the 163 brownfield sites and their hypothetical counterparts. The values varied widely from site to site, as would be expected given the wide range of characteristics of the various locations. For 90-95% of the sites, however, the brownfield locations had environmental performance superior to their conventional or greenfield counterparts. The results were averaged for each municipal area and are shown in Exhibit 1-2. Averaging the results for the five municipal areas indicates that:

- Automobile use by residents and employees at brownfield locations is estimated to be substantially lower than at the alternative locations:
  - Daily vehicle miles traveled per capita would be 32-57% lower.
  - Daily vehicle trips per capita would be 16-38% lower.
  - Personal vehicle energy use per capita would 32 - 57% lower.
- Brownfield redevelopments produce 32 - 57% less carbon dioxide emissions per capita relative to conventional developments.
- Brownfield redevelopments produce 32 - 57% less air pollutant emissions per capita relative to conventional developments.
- Stormwater runoff from brownfield redevelopments is estimated to average 43 - 60% less than the greenfield alternatives.

Exhibit 1-2. Comparison of Environmental Performance of Brownfield and Conventional Development in Five Municipal Areas

Environmental Indicator	Units	Percent Difference for Brownfields as Compared to Conventional (Conventional less Brownfield Scenarios as a Percent of Conventional)					
		Seattle Area	Twin Cities Area	Emeryville Area	Baltimore Area	Dallas-Fort Worth Area	Average
Home based vehicle miles traveled	mi/capita/day	67%	32%	53%	37%	NA	45%
Non-home-based vehicle miles traveled	mi/capita/day	37%	34%	45%	53%	NA	43%
Total vehicle miles traveled	mi/capita/day	57%	32%	49%	42%	53%	47%
Home based vehicle trips	mi/capita/day	11%	13%	36%	NA	NA	20%
Non-home based vehicle trips	mi/capita/day	29%	19 %	40%	NA	NA	30%
Total vehicle trips per capita	trips/capita/day	19%	16%	38%	NA	24%	24%
Personal vehicle energy use	MMBtu/capita/yr	57%	32%	49%	42%	53%	47%
Residential structural energy use	MMBtu/capita/yr	6%	NA	NA	NA	NA	NA
Carbon dioxide (CO_2) emissions	lbs/resident/yr	57%	32 %	49%	42%	53%	47%
Air pollutants (NOx, HC, & CO)	lbs/resident/yr	57%	32%	49%	42%	53%	47%
Land consumption	acres	50 to 75%	50 to 75%	50 to 75%	50 to 75%	50 to 75%	50 to 75%
Stormwater runoff	acre feet/yr	49 to 64%	48 to 69%	27 to 45%	48 to 70%	43 to 52%	43 to 60%
Nitrogen	lbs/yr	57 to 71%	75 to -17%	53 to 69%	1 to 74%	66 to -48%	9 to 71%
Phosphorous	lbs/yr	64 to 78%	81 to -36%	77 to -113%	79 to -13%	77 to -55%	-31 to +78%
Suspended solids	lbs/yr	65 to 79%	26 to 83%	79 to -11%	30 to 80%	79 to -3%	21 to 80%
Biological oxygen demand	lbs/yr	64 to 78%	67 to 83%	54 to 77%	65 to 78%	59 to 78%	62 to 79%
Chemical oxygen demand	lbs/yr	65 to 79%	71 to 84%	60 to 77%	61 to 78%	66 to 79%	65 to 79%
Oil and grease	lbs/yr	65 to 79%	71 to 84%	60 to 77%	65 to 80%	67 to 80%	66 to 80%
Metals (average for .lead, copper, zinc, cadmium, chromium, nickel)	lbs/yr	60 to 74%	65 to 78%	53 to 64%	62 to 77%	54 to 68%	59 to 72%

***Notes*:** MMBtu = millions of British thermal units; mi = miles; lbs = pounds; yr = year; CO_2 = carbon dioxide; CO = carbon monoxide; HC = hydrocarbons; NOx nitrogen oxides; NA = data not available; Non-home vehicle miles and trips per capita are calculated per employee; ranges in stormwater indicators are due to a range of greenfield site acreages and land use types. Loadings of some water pollutants in some regions are higher under the brownfields development scenario; on average they are lower.

- Brownfield redevelopments also produce substantially lower loads of all pollutants studied, averaging from 9% to 80% for conventional pollutants and 59% to 72% for metals. [2]
- Based on a literature review, it is estimated that brownfield sites typically accommodate the same number of homes and businesses on about ¼ to ½ the land typically used at corresponding conventional sites.

These results are generally consistent with the land use patterns and urban form measures for the areas studied. On average, neighborhoods with the brownfield sites had higher development density (population, dwelling units, and employees per gross acre), more travel accessibility to other areas (in terms of distance and travel time), and better access to transit than the areas where the conventional counterparts are located. Exhibit 1-3 summarizes these measures. For example, the Seattle neighborhoods with the brownfields have, on average, twice the population density of the conventional counterpart areas. In addition, the percentage of the population within ¼ mile of transit in the brownfield neighborhoods is more than double that of the conventional locations, on average.

1.4 Discussion

The results in Section 1.3 generally are in line with other studies that compare the environmental performance of brownfield or infill development with conventional and greenfield development. More than a dozen such studies were reviewed and the percentage improvement in vehicle miles traveled is within the range estimated by those studies (Appendix A). The previous studies generally addressed one or several properties and examined specific characteristics of each property, as well as the hypothetical counterpart greenfield sites in detail. This study examines 163 properties in five cities, but with less detail about each property than the previous studies, as the ultimate goal is to determine the feasibility of developing national estimates of environmental impacts.

The results of this study are also consistent with other studies that have evaluated the relationship between urban built environment and vehicle use and air emissions using data for wider geographic areas, such as counties and metropolitan statistical areas. A well-researched summary of this literature is included in the report *Growing Cooler: The Evidence of Urban Development and Climate Change* (Ewing 2008). The study estimated that, with more compact development, people drive 20 to 40% less.

Another study used the 1999 Puget Sound Household Travel Survey and land use measures to examine the relationship between land use patterns and travel and vehicle emissions (Frank 2005). The findings suggest that residents make travel choices based on several factors, most of which are related to time spent traveling, including wait times, which are, in turn, related to land use patterns. Increased levels of mixed-use development, retail density, and street connectivity were associated with lower per capita emissions and an increased tendency to walk.

Although the results for each city show significant positive environmental outcomes from building on brownfields, the estimates vary from city to city. This variation is not readily explained by a direct comparison of the average urban form indicators, such as population density, employment density, dwelling units per gross acre, and accessibility measures. Direct comparisons of these variables are confounded by the facts that the results are first differences between the conventional and brownfield scenarios (i.e., the conventional scenario less the brownfield scenario) and that there are many factors that vary among cities, such as geographical barriers, socioeconomic characteristics, the existence and effectiveness of mass transit, the physical form of existing conventional and greenfield areas, and

[2] These estimates do not include the potential reduction in pollutant loads from cleanup of the brownfield properties.

economic growth. For example, because Seattle is surrounded by many bodies of water and mountains, some of the outlying areas are accessible to the central city or other destinations only by bridge, ferry, or circuitous routes. This fact may explain why the results for the Puget Sound area indicate greater reductions in vehicle miles traveled and emissions under the brownfields redevelopment scenario than for the other cities. Minneapolis has the lowest percentage net improvement in environmental performance (e.g., 32% lower vehicle energy use), although the ratios of density and other urban form indicators would indicate that that it should be closer to the other four cities in this study (40 – 50%). This is partly explained by the fact that people in the brownfield areas tend to drive more than those in other cities. People in the outer areas tend to drive about as much as those in the outer areas of the other regions.

Despite the environmental advantages of more compact, accessible development, the extent of implementation of smart growth policies may be limited by the demand for urban development. The *Growing Cooler* study and a recent EPA study (Thomas 2009) indicate that, in many cities, there is strong demand for housing in central cities and core suburban areas relative to suburban and exurban areas. The EPA study found that the percentage of houses built in urban areas has been increasing dramatically, relative to the outer areas. Residents show a preference for neo-traditional urban design, and relatively higher use mix and density. The fact that the housing market has been receptive to smart growth policies indicates that in the current real estate market, there is potential for leveraging smart growth policies in these cities. A number of factors contribute to this trend, such as demographics, local growth planning, lifestyle changes such as the growing popularity of walkable communities, and lifecycle changes of individuals (e.g., baby boomers who, upon becoming empty nesters, wish to move from the suburbs to the city). Some cities with weak growth policies also exhibit this trend. The study also found considerable variation in characteristics such as market-share trends among the municipal areas, as does this study.

1.5 Other Impacts

There are a number of other important environmental and human health benefits that result from compact development that are not addressed in this study.

- Infrastructure, such as roads and utilities, to support brownfield redevelopment generally requires less land per capita and results in less stormwater runoff than infrastructure needed to support a similar amount and type of conventional development. Generally, the lower the population density, the more roads and highways are called for to connect trip origin and destination points. On the other hand, residents and employees in more efficiently located, compact communities typically drive less and have opportunities to use other transportation modes. The resulting lower demand for highways implies fewer lane-miles and less road surface and, consequently, lower stormwater runoff, energy consumption, and cost for construction, maintenance, snow removal, and highway safety programs. Studies have shown that infrastructure costs for conventional development are significantly higher than that of infill areas.
- Greenfield conversion can have climate change and other ecological effects. Since forests generally sequester carbon, their elimination can result in higher levels of CO_2 in the atmosphere (EPA 2010). The development of pasture and forest can reduce or fragment habitat areas necessary for species to maintain a minimum viable population and to maintain biodiversity.
- A number of studies have shown that compact development also provides health benefits by (a) reducing air pollutant emissions; and (b) providing more opportunities for physical activity, such as walking and biking, which generally are associated with improvements in public health. (Frank 2005, Ewing 2003, McCann 2003, Sturm 2004).

Exhibit 1-3. Comparison of Measures of Urban Form of Brownfield and Conventional Development in Five Municipal Areas

Land Use and Urban Form Indicator	Units	Percent Difference for Brownfields as Compared to Conventional (Conventional less Brownfield Scenarios as percent of Conventional)					
		Seattle Area	Twin Cities	Emeryville Area	Baltimore Area	Dallas Area	Average
Population density	Persons / gross acre	166	519	54	91	15	169
Employment density	Employees / gross acre	1,086	176	130	-11	186	313
Dwelling density	DU/gross acre	154	450	127	96	8	167
Jobs-to-housing balance	Jobs/DU	51	40	67	3	122	57
Transit adjacency to housing	% population within 1/4-mi	169	245	45	NA	185	161
Transit adjacency to employment	% employees within 1/4-mi	113	249	45	NA	166	143
% total region HH w/in 10 min. walk from TAZ center	%	72	75	85	NA	2	59
% total region HH w/in 30 min. transit ride from TAZ center	%	366	9,470	174	122	NA	2,533
% total region HH w/in 6 mi. by SOV from TAZ center	%	318	474	102	115	36	209
% total region empls w/in 10 min. walk from TAZ center	%	1,053	309	97	16	307	356
% total region empls w/in 30 min. transit ride from TAZ center	%	3,630	10,409	485	NA	NA	4,751
% total region empls w/in 6 mi. by SOV from TAZ center	%	1,283	346	118	139	115	400

Notes: MMBtu = millions of British Thermal Units; DU = dwelling unit; HH = households; SOV = single occupancy vehicle; TAZ = traffic analysis zone or travel analysis zone; mi = miles; lbs = pounds; yr = year; CO = carbon monoxide; HC = hydrocarbons; NOx = nitrogen oxides

Negative value indicates that the brownfield value is lower.

- Brownfield and infill residences require less energy per capita than conventional residences. This study examined this phenomenon for the Seattle area, the only one of the five regions studied for which the necessary data was available. Residential energy consumption for brownfield properties in Seattle averages 6% lower than that of the alternative sites.

1.6 Implications

The study results have implications for EPA's Brownfields Program and development planners at the state and local levels:

- Previous EPA Brownfields grant funds to the five cities have facilitated development with more positive environmental outcomes compared to the prevailing development trends in their metropolitan areas.
- Further examination of this data may inform EPA regarding providing outreach or engaging in other efforts to encourage positive environmental outcomes.
- The results of this study strongly endorse smart growth practices and may serve to encourage and contribute to outreach efforts by EPA regions and state and local officials.
- It is feasible to quantify the environmental impact of the built environment in a region, using data elements similar to those in this study, although data sources may differ by region. Such estimates may contribute to the efforts of local, state, and regional planners and officials.
- It is probable that if this analysis were repeated at another location, especially in large metropolitan areas, it would obtain similar results. Nevertheless, the estimates for these five regions cannot simply be extrapolated to all brownfields properties in the country.

This report does not infer the quantitative estimates to other jurisdictions. However, the findings of this study, taken together with other studies discussed above, indicate that there are substantial environmental advantages to brownfield redevelopment as compared to conventional and greenfield development.

The methodologies used in this study are subject to a number of limitations and caveats. These are discussed in Appendix B, Methodology.

2. Seattle Area

The analysis of the Seattle area follows the basic methodology outlined in Section 1 and described in more detail in Appendix B. It was based on a set of 28 brownfield properties in Seattle that had benefited from U.S. EPA Brownfields Program funding and had redevelopment completed or under way. These parcels represent a variety of uses and are scattered throughout Seattle, with some concentration in industrial or former industrial areas.

2.1 Brownfield Redevelopment Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in the city, and measures of urban form, energy use, air emissions, and estimated stormwater runoff and pollutant loads from the brownfield locations.

Seattle Brownfield Properties: Using EPA's ACRES database, the EPA Region 10 web site, and other online sources, over 70 brownfield properties in the Seattle area were initially identified. Several sources, including the King County web site, the Environmental Coalition of South Seattle (ECOSS), tax assessor records, and building permit files, were consulted to determine property location, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. This analysis showed that 28 properties had reuse completed, under way, or planned. Properties for which there were firm specific reuse plans in place were considered as having development under way. To facilitate the calculations, data for four adjacent properties with the same use type (multi-family residential) were consolidated into one hypothetical larger parcel. The resulting 25 parcels are listed in Exhibit 2-1, and their locations are shown in Exhibit 2-2.

Many of the redeveloped brownfield sites in Seattle are small parcels with small business establishments. The average parcel size is only 3.5 acres. When one very large site is removed, the average of the remaining 24 sites is only 1.2 acres. Details about these sites are sometimes limited to anecdotal information and informal records of local officials.

Air Quality Impacts and Personal Vehicle Energy Use: Data used to estimate automobile use, energy consumption, and air pollutant emissions associated with the brownfield locations were provided by the Puget Sound Regional Council (PSRC), which is responsible for growth management and transportation planning in the approximately four-county region (Exhibit 2-3). For growth modeling purposes, PSRC subdivides the region in two ways: (1) a grid of 2,200-acre cells known as subareas;[3] and (2) traffic analysis zones (TAZs) of varying size, all smaller than subareas. Some of the environmental indicators were available at the subarea level, while others were available at the TAZ level. The environmental and urban form characteristics of the subareas and TAZs were described according to TAZ indicators already scored by PSRC and the subarea indicators modeled by PSRC using INDEX planning support software (Allen 2008, EPA 2001b). Residential structural energy use was also tabulated, although data for this indicator were not available for the other four metropolitan areas studied. Urban form indicators include density measures (population, dwelling units, and employment per gross acre), jobs-to-housing balance, and several transportation accessibility indicators. For the other four regions, all calculations were at the TAZ level.

[3] The 2,200-acre cells are aggregations of 5.5-acre cells used in the UrbanSim model. UrbanSim is the regional planning model used for the Puget Sound area.

Exhibit 2-1. Seattle Brownfield Properties Studied

ID	Property	Address	Parcel Size (Acres)	Building Size (SF)	Past Use	Present Use	Future Use
1	Rainier Court Development	NW of Rainier Ave. S & S. Charlestown Street	7.0	20,000 + 500 DUs	N/A	N/A	500 units affordable senior & family housing; 20,000 sf. commercial
2	Colman Building	2203 E. Union St.	0.37	N/A	Apartments above commercial	Vacant	Residential/commercial
3	Kwick Cleaners	2701 15th Ave S	0.28	5,746	Dry cleaner	Retail bakery	No change expected
4	Coleman Creosote Property	333 Elliott Avenue W	1.17	6-stories	Wood treating facility	Office building	Office space
5	Pier 1 Property	2130 Harbor Ave. SW	2.51	1-story	Seafood processing, metal fabrication	Seafood processing	Residential/commercial condominiums with greenspace
6	Ballard Oil Bulk Plant	1101 NW 45th Street	0.88	N/A	Bulk oil storage	Pavingstone Supply Co.	Continued outdoor commercial/retail
7	Georgetown Gasoline Station	6527 4th Ave S	0.18	N/A	Gas station	Check cashing store	No further change expected
8	Central Painting	4749 W. Marginal Way S	0.4	N/A	Commercial painting	Stone countertop finishing	No further change expected
9	Crosby Frame & Axle Property	8621 14th Ave S	0.14	N/A	Auto repair/gas station	Sewing shop	No further change expected
10	Pederson Property	8520 14th Ave S	0.12	N/A	Garage & gas station	Produce market	No further change expected
11	Ballard Auto Wrecking	1515 NW Leary Way	0.68	1-story	Auto wrecking yard	Vacant lot for lease	Commercial
12	Tsubota Industrial Supply	1837 15th Avenue W	1.75	N/A	Steel fabrication, industrial sales	Mostly vacant	Commercial/retail development planned
13	Bill's Tires	4910 NW Leary Way	0.13	1,157	Gas station/tire store	Station Bistro rest	No further change expected
14	General Disposal Site	1415 Ballard Way NW	1.91	30,500	Garbage truck maintenance facility	Under construction for new dev.	Mixed retail/commercial
15	Former Lloyd's Rocket Gas Sta.	110 Boren Avenue S	0.33	2,038	Gas station & garage	New restaurant	No further change expected
16	Ninth & Jefferson Street Building	925 James Street	0.34	N/A	Former dry cleaner and other commercial	Medical facility	Medical facility
17	SeaCon Property	9530 10th Ave S	4.43	N/A	Vacant-contaminated fill	Ind./warehouse/ off.	No further change expected
18	North Bay at Terminal 91	2001 West Garfield Street	57	N/A	Marine terminals, bulk oil storage, auto storage, seafood processing	Marine terminal is active, but uplands mostly pending dev	Mixed industrial, commercial
19	Doc Freeman Properties	3831 Stone Way N	0.14	2,750	Commercial rental	Office space	No further change expected
20	Doc Freeman Properties	3939 Stone Way N	0.27	2,400	Commercial retail	Indoor Garden Center-retail	No further change expected
21	Chrome Plating Works	601 North 35th Street	0.2	NA	Metal plating	Burt Sugar retail consignment store	No further change expected
22	All Metal Fabricators	2952 1st Avenue S	0.83	N/A	Warehouse	Retail use	Commercial/retail
23	NW Enviroservice 1st Ave. So. Spill	8105 1st Avenue S	2.12	N/A	Truck repair shop	Service garage for trash trucks	No further change expected
24	Advanced Electroplating Inc.	9585 8th Ave. S	1.26	30,500	Metal plating	Industrial/Gen. Pur-pose contractor	Same
25	Kvichak Marine	469 NW Bowdoin Place	2.08	42,100	Steel fabrication	Alum. boat mfg .	No further change expected

Notes: NA = Not available

Source: U.S. EPA, ACRES database, King County, WA, and Environmental Coalition of South Seattle.

Exhibit 2-2. Locations of 25 Brownfield Sites in Seattle

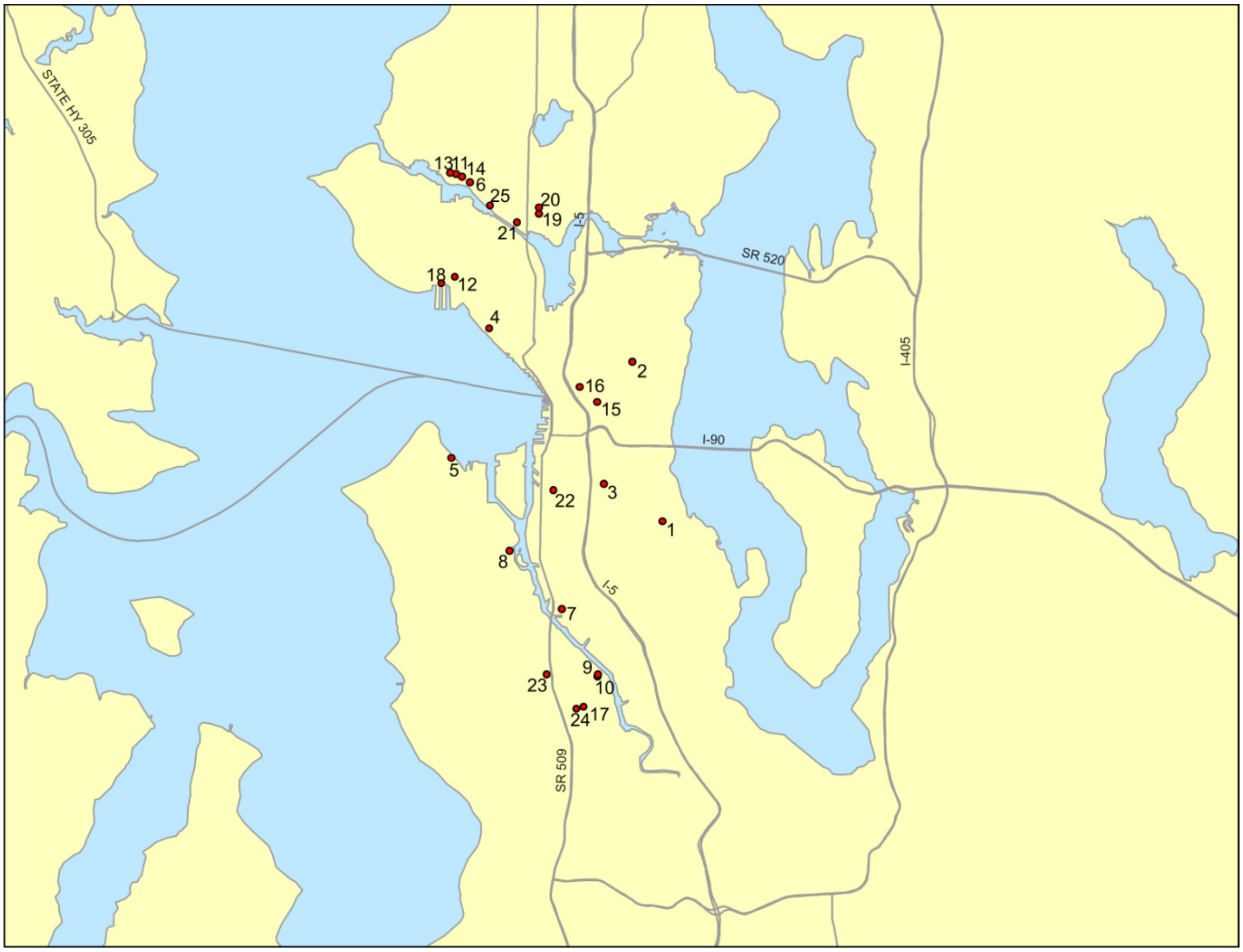
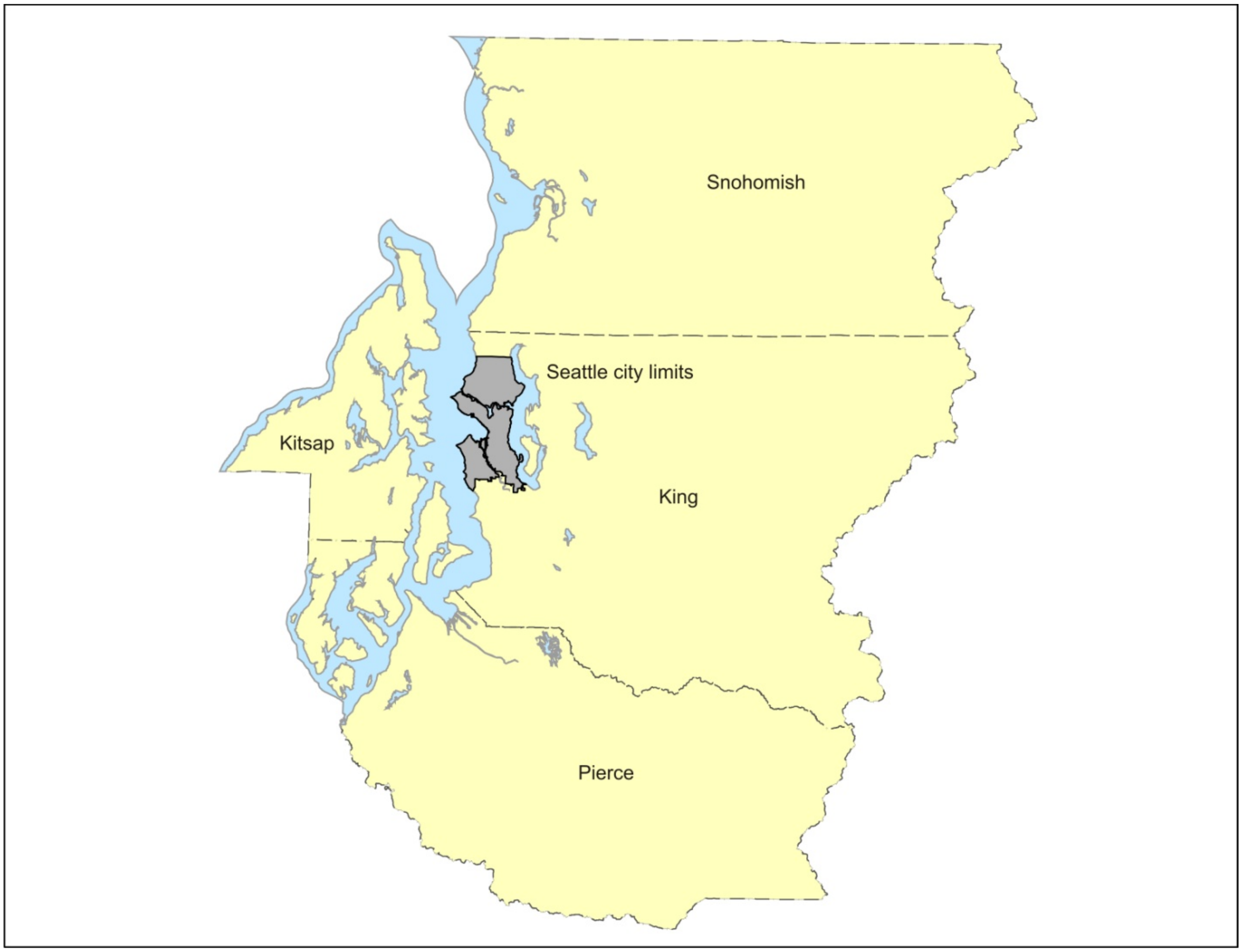


Exhibit 2-3. Puget Sound Regional Council Planning Area



The urban form indicators are not directly used in the calculations of VMT, air pollutant emissions, and stormwater runoff; these indicators are provided as additional metrics that are considered to be related to travel efficiency in the region.

Water Quality Impacts: The Long-Term Hydrologic Impact Assessment (L-THIA) watershed management model was used to estimate stormwater runoff and pollutant loads for each site. The model calculates runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. L-THIA contains data on average county precipitation, generally accepted soil curves for each type of land use and soil (USDA 1986), and hydrologic soil group. Data on site location, parcel size, and land use type, shown in Exhibit 2-1, were entered into the model. Appendix B describes the rationale for using this model, how it was applied, and some important assumptions.

The estimated runoff from former uses of the Seattle brownfield sites was compared to those of the redeveloped brownfield sites. Seattle's developed brownfields were estimated to have 3.5% more runoff than that from the former uses. This small change is due to parcels shifting from one developed use to another, such as from industrial to commercial. A number of parcels did not change their land use classification. These differences are insignificant compared to the total amount of runoff from the alternative sites.

Appendix B provides further detail on the application of L-THIA, key assumptions, and limitations of the approach.

2.2 Alternative Conventional Development Scenario

The alternative conventional scenario assigned locations that were reasonable for the same type of development, if the development had not occurred on the brownfields, and estimated the environmental performance of these locations.

Alternative Conventional Locations: For each brownfield site, an alternative location was assigned based on recent development patterns in the region. The development counterpart for each brownfield site was assigned to one of the top 5% fastest growing areas in the four-county region (about 73 TAZs and census tracts). The fastest growing areas were determined from the number of residential building permits issued from 2000 to 2005 and from the change in employment from 1995 to 2000, the latest period for which data were available.[4] While information on the dates of the development of these properties is imprecise, these time periods are believed to be approximately when redevelopment decisions and other activities took place for a number of the sites. The high-growth areas are shown in Exhibit 2-4. An additional analysis using the top 10% of the TAZs also showed a similar distribution among outlying areas. Alternative locations for each of the 25 brownfield sites are shown in Exhibit 2-5. These locations were selected from among the 73 high-growth areas. The use of a statistical selection procedure helped to ensure impartiality.

[4] To reflect growth in both employment and residents, the 25 brownfield sites were divided into two groups according to whether, based on their redevelopment use, they were more likely to be located in, or economically linked to, a residential area (13 sites) or a non-residential area (12 sites). For the residential-related counterpart sites, the fastest growing TAZs were based on residential building permit volume. The fastest growing non-residential areas were identified by census tract employment data.

Exhibit 2-4. High Growth TAZs and Census Tracts in the Seattle Area

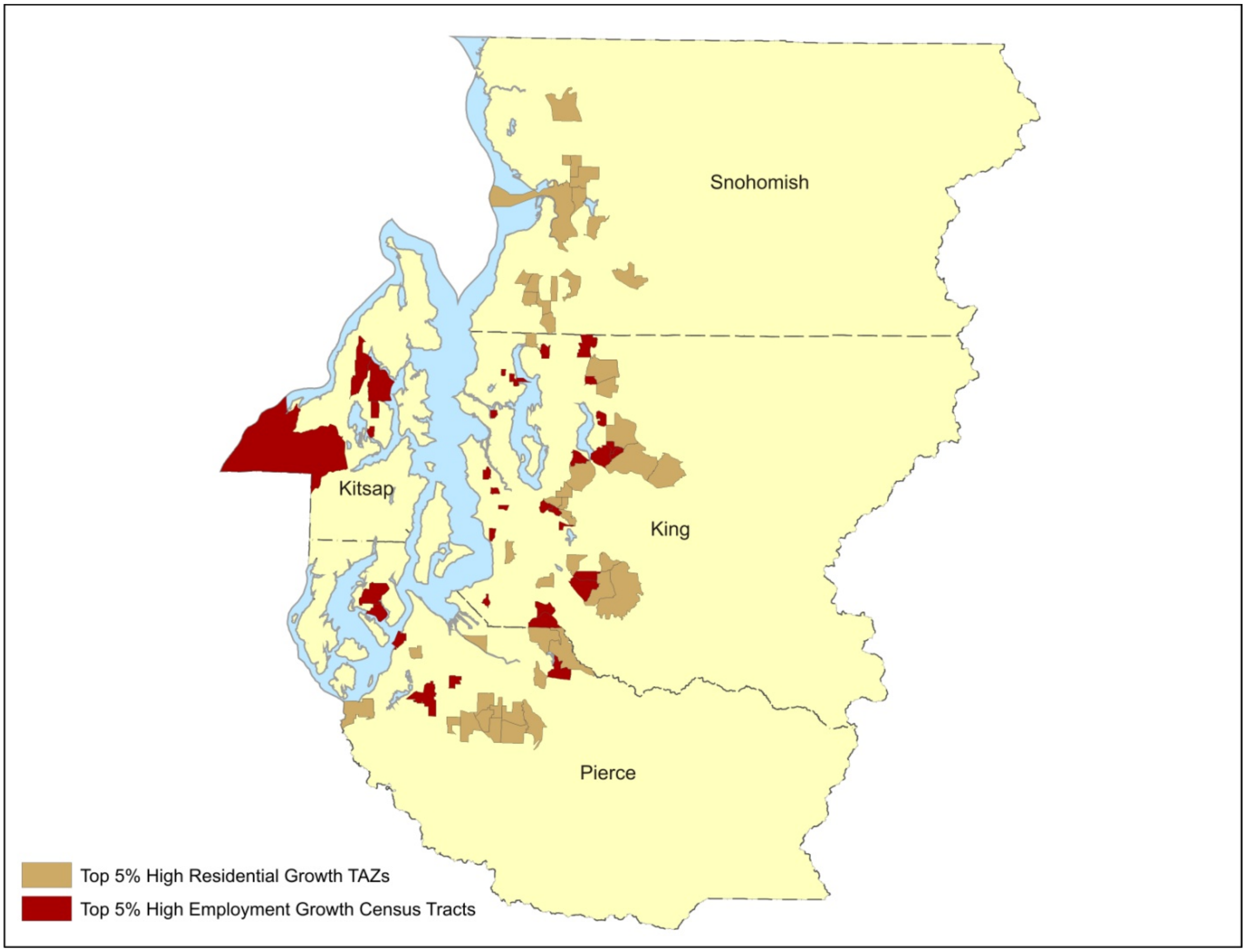
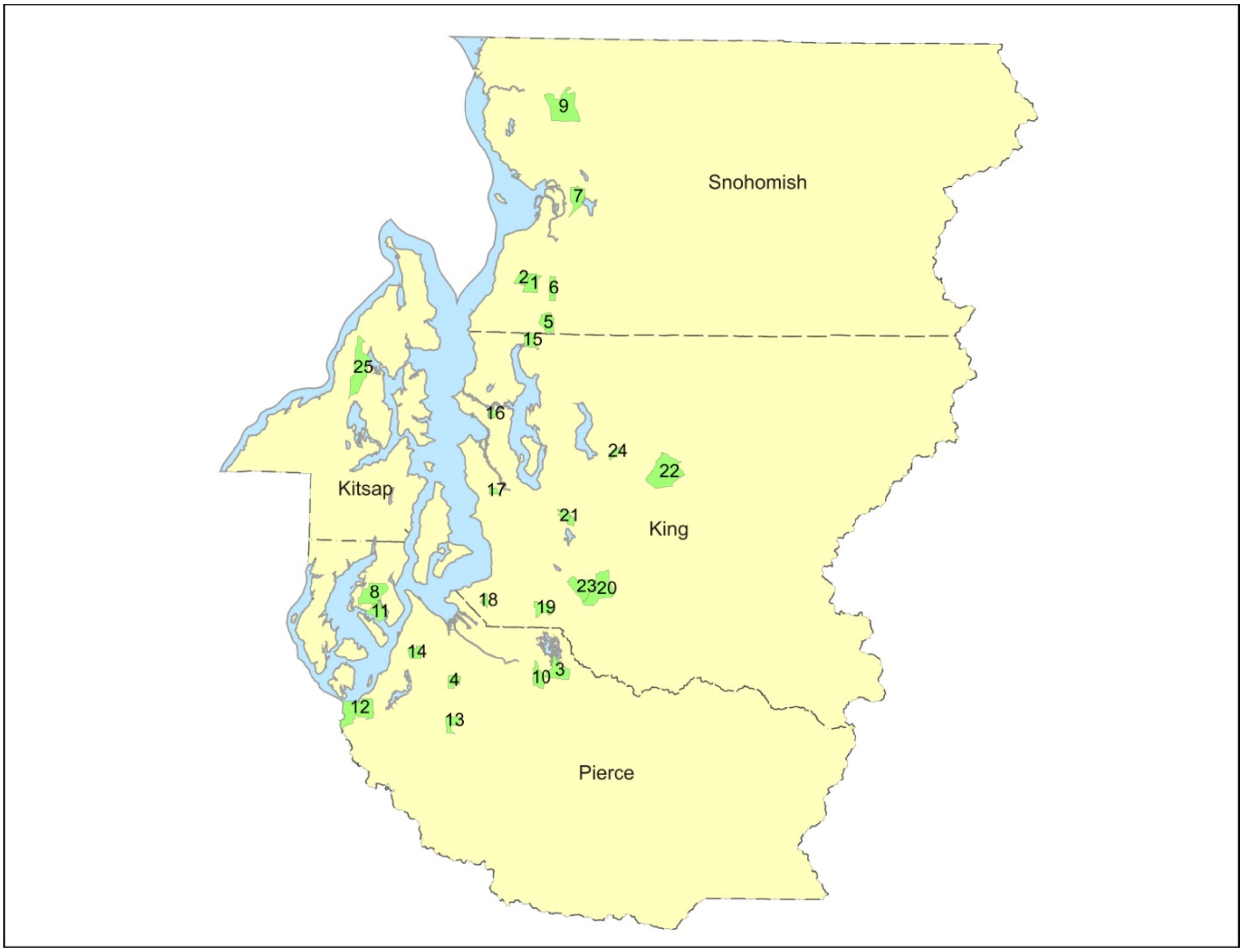


Exhibit 2-5. Alternative Conventional Locations in the Seattle Area: 25 Sites



Alternative Conventional Development Size: Development generally consumes more acreage in suburban and rural areas than in more dense, urban areas, due to building practices, parking requirements, and typically lower land cost. Based on the methodology described in Appendix B, it was assumed that the conventional/greenfield sites would generally require two to four times the acreage of their brownfield counterparts. Planners at PSRC, based on their professional judgment, indicated that this range is reasonable (PSRC 2006). Land use decisions are inherently influenced by a number of site-specific factors. As a result, there is a wide variation in the amount of land consumed by similar uses in different areas, or even properties within close proximity. Thus, the average acreage multiplier of two is used for a more conservative estimate, and an average of four is used for an upper bound.

Air Quality, Energy Consumption, and Urban Form: Using information on the conventional locations, acreage, and types of use, the environmental characteristics of these locations were described according to indicators scored by the PSRC transportation and land use models, in a procedure identical to that described above for the brownfield sites.

Water Quality: Using information on the alternative development locations, which were assumed to be greenfields for the stormwater modeling, acreage, and categories of land use (e.g., commercial, residential, pasture, forest), the stormwater runoff and pollutant loads for these locations were estimated with the L-THIA model in a procedure identical to that described above for the brownfield sites.

It was assumed that new construction would take place either in a former vacant pasture area or in a former forested area.[5] Using two land use categories provides a range of acceptable values rather than a single estimate. This approach is appropriate, as the precise location of the greenfield site within the TAZ or census tract is unknown. To obtain the net new runoff contribution of the greenfield development, the existing runoff (pasture or forest area footprint) was subtracted from the runoff expected from the developed uses, which were commercial, industrial and residential. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites were also factored in. These calculations are described in greater detail in Appendix B.

2.3 Comparison of Brownfield and Conventional Scenarios

For each site pair, the estimated indicators were compared, and totals for all sites were averaged. The results of the air quality and energy analysis were generally expressed in terms of percent difference in VMT and emissions associated with the brownfield site compared to its conventional alternative on a per capita basis. The results of the stormwater runoff analysis were expressed in terms of percent difference in stormwater runoff and pollutants for brownfields in the group of 25 site pairs. A number of limitations and caveats apply to this comparison. These are discussed in Appendix B, Methodology.

Exhibit 2-6 compares the environmental indicators for the averaged totals of all the site pairs. Twenty six of the indicators relate to urban form, travel, energy use, and air emissions; and nine variables address land use, stormwater runoff, and water pollutants. In general, the brownfield locations demonstrate substantially greater land-use and location efficiency, less auto dependency, and lower personal vehicle energy use, air pollutant emissions, and stormwater runoff and pollutant loads.

5 The predominant undeveloped land use in the region is forest. Since the precise locations of the alternative greenfield sites within the census tracts are unknown, this range was used to account for the possibility that some projects may be located on pasture. L-THIA's Basic module offers three land use categories for undeveloped land: forest, pasture/grassland, and agricultural.

Exhibit 2-6. Comparison of Environmental Indicators in the Seattle Area: Average Differences Between 25 Site Pairs

		Brownfield Average	Conventional Average	Percent Change (Conventional less Brownfield) (a)
Accessibility Indicators				
Households in TAZ		1,210	1,621	25%
% total region HH w/in 10 min. walk from TAZ center		0.09%	0.05%	72%
% total region HH w/in 30 min. transit ride from TAZ center		0.70%	0.15%	366%
% total region HH w/in 6 mi. by SOV from TAZ center		9.16%	2.19%	318%
Employment in TAZ		3,666	809	353%
% total region emps w/in 10 min. walk from TAZ center		0.21%	0.02%	1,053%
% total region emps w/in 30 min. transit ride from TAZ center		2.00%	0.05%	3,630%
% total region emps w/in 6 mi. by SOV from TAZ center		19.13%	1.38%	1,283%
Environmental Performance Indicators	**Units**			
Population density	persons/gross ac	7.7	2.9	166%
Transit adjacency to housing	% pop. w/in 1/4-mi	96.7	36.0	169%
Jobs-to-housing balance	jobs/DU	3.0	0.5	51%
Employment density	emps/gross ac	15.5	1.3	1,086%
Transit adjacency to employment	% empl w/in 1/4-mi.	94.8	44.5	113%
Nitrogen oxides (NOx) emissions	lbs/resident/yr	15.6	36.0	57%
Carbon dioxide (CO_2) emissions	lbs/resident/yr	2,892	6,681	57%
Hydrocarbon (HC) pollutant emissions	lbs/resident/yr	30.3	69.9	57%
Carbon monoxide (CO) emissions	lbs/resident/yr	233.9	540.4	57%
Home-based vehicle miles traveled	mi/capita/day	5.6	17.2	67%
Non-home based vehicle miles traveled	mi/capita/day	5.8	9.2	37%
Total vehicle miles traveled	mi/capita/day	11.4	26.4	57%
Home-based vehicle trips	trip/capita/day	1.4	1.6	11%
Non-home based vehicle trips	trip/capita/day	0.9	1.2	29%
Total vehicle trips	trip/capita/day	2.4	2.8	19%
Dwelling density	DU/gross ac	2.4	0.9	154%
Residential structural energy use	MMBtu/capita/yr	36.6	38.9	6%`
Personal vehicle energy use	MMBtu/capita/yr	26.00	60.07	57%
Stormwater Runoff and Pollution Indicators (Average of All 25 Site Pairs)	**Percent Change (Conventional/Greenfield less Brownfield) (a)**			
	Pasture (Grasslands)		**Forest**	
	Low Bound (2x Brownfield Acres)	**Upper Bound (4x Brownfield Acres)**	**Low Bound (2x Brownfield Acres)**	**Upper Bound (4x Brownfield Acres)**
Land area (Acres)	50%	75%	50%	75%
Annual runoff	49%	60%	53%	64%
Nitrogen	57%	70%	59%	71%
Phosphorous	64%	78%	64%	78%
Suspended solids	65%	79%	65%	79%
Biological oxygen demand	64%	78%	64%	78%
Chemical oxygen demand	65%	79%	65%	79%
Oil and grease	65%	79%	65%	79%
Metals (average for copper, zinc, cadmium, chromium, nickel)	60%	72%	62%	74%

Notes:

TAZ = traffic analysis zone; HH= household; Ac = acre; Pop = population; SOV = single occupancy vehicle; DU = dwelling unit; MMBTU = millions of British Thermal Units

(a) Percentage change calculated as: [(Value for conventional – Value for brownfield) / Value for conventional] x 100

2.3.1 Air Emissions and Personal Vehicle Energy Use

The average brownfield scores were superior for all indicators except jobs-to-housing balance. The primary reason for this counter-intuitive finding is that the brownfield TAZs tend to be in non-residential areas, with high jobs/dwelling unit ratios (average 3.0). The 0.7 average for the conventional TAZs is closer to a balanced score. Although this ratio is often considered to be related to travel efficiency, the data in an area could show a very balanced ratio, while at the same time, residents are traveling elsewhere to work and regional employees are drawn from other places.

The calculations show that nearly all redeveloped brownfield sites result in substantially better environmental performance than similar conventional development. These results (Exhibit 2-6) indicate the following:

- Brownfield sites accommodated the same number of homes and businesses on about one-fourth to one-half the land typically used at corresponding conventional sites.
- Automobile use by residents and employees at brownfield locations is estimated to be substantially lower than at the alternative locations.
  - Average daily vehicle miles traveled per capita would be 57% lower.
  - Average daily vehicle trips per capita would be 19% lower.
  - Personal vehicle energy use per capita would be 57% lower.
- The brownfield redevelopment areas average 57% lower air pollutant emissions per capita relative to conventional development.
- Residential energy use in the brownfield TAZs was also lower by 6%.

The positive environmental indicator values at the brownfield locations stem from the fact that the brownfield neighborhoods in this study are denser and more accessible by most measures. Density is measured primarily by the number of residents, households, or employees per gross acre. Generally, the denser an area, the shorter the distance to various destinations for shopping, recreation, employment and other purposes. Population density for the average brownfield TAZ in this study is about twice that of the average alternative TAZ. Employment density in the average brownfield TAZ is seven times that of the average alternative TAZ.

Accessibility is measured primarily in terms of time required to travel between key origin-destination points within the region. Based on the indicators in Exhibit 2-6, people living and working in the brownfield neighborhoods have substantially more accessibility to other neighborhoods and to points within their TAZs than those in their conventional counterparts. For example, the percentage of all households in the four-county region within a 30-minute transit ride of the center of the average brownfield TAZ is more than seven times that of the average conventional TAZ. Nineteen percent of total regional employees are within six miles by single occupancy vehicle (SOV) from the TAZ center for the average brownfield TAZ. The figure for conventional TAZs is 1.4%.

The primary air quality indicators in this study are per-resident emissions of nitrogen oxides, carbon dioxide, carbon monoxide, and hydrocarbons. Lower emissions are considered a positive environmental outcome, and more intensive development in more central areas usually results in lower per-capita emissions than if the same amount of development was located in less dense, less accessible areas. However, although total emissions in a region may be lower due to more compact and location-efficient development patterns, a particular intensive development can result in local "hot spots" of one or more pollutants. Hot spots are local areas of very high concentrations that may present a health or environmental risk or cause an area to fall out of compliance with air pollutant levels.

Some pollutants, such as carbon monoxide, are primarily a local health concern. Others, such as carbon dioxide, are greenhouse gases, which contribute to climate change. Some pollutants, such as nitrous oxide, can have local health impacts and are also greenhouse gases. None of the brownfield development projects in this study is large enough or has enough industrial or transportation activity to be a regional concern on its own. However, analysis of other development in the area was not conducted to see if, combined with the other projects, there might be significantly elevated levels of emissions.

2.3.2 Stormwater Runoff and Pollutant Loads

Using the lower-bound (more conservative) footprint, runoff in acre feet due to development of brownfield sites would be 49% lower than if their counterpart sites were in pasture (grassland) areas. Using the high-footprint estimate, it would be 60% lower. If the counterpart sites were in forested areas, the differences were 53% and 64%, respectively. Loads for conventional pollutants, such as nitrogen, phosphorous, suspended solids, biological oxygen demand, and chemical oxygen demand range from 65 to 79% lower.

Based on the calculations using L-THIA, stormwater runoff from redeveloped brownfields in the City of Seattle is estimated to be about 3.5% greater than that from the former uses. This result is caused by shifts in land use from one type of developed use to another, such as from industrial to commercial. In a separate calculation, runoff was estimated at the alternative locations with and without development, without considering runoff at the brownfield sites. If left undeveloped, the 25 alternative sites in Seattle would produce 76 - 82% less runoff than if they were developed.

Further explanation of the methodology used to develop these estimates as well as issues to consider in interpreting results and limitations are provided in Appendix B.

2.4 Sensitivity Analysis

To test the robustness of the estimates, a second group of 25 alternative sites (Alternative B sites) was selected using a methodology similar to that for the first group. The statistical site selection procedure used to select the conventional sites from among the fastest growing TAZs helped to ensure that the process was impartial. Because these sites were also selected from the fastest growing areas in the region, they generally reflect the prevailing development patterns in the four-county region. In this analysis, the results for the individual sites differed from the first group of sites. However, the 25-site averages of the environmental indicators were within a few percentage points of the first set of sites, thereby supporting the initial results.

3. Minneapolis-Saint Paul Area

The analysis of the Minneapolis-Saint Paul area follows the basic methodology outlined in Section 1 and described in more detail in Appendix B. It was based on a set of 37 brownfield properties in Minneapolis and Saint Paul (Twin Cities), Minnesota that benefited from U.S. EPA Brownfields Program funding and had redevelopment completed or under way. These sites represent a variety of uses and are scattered throughout the Twin Cities, with 25 in Minneapolis and 12 in Saint Paul.

3.1 Brownfield Redevelopment Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in the city, and measures of urban form, energy use, air emissions, and estimated stormwater runoff and pollution loads from the brownfield locations.

Minneapolis-Saint Paul Brownfield Properties: Using EPA's ACRES database, the EPA Region 5 web site and other online sources, 86 brownfield properties in the Twin Cities were initially identified. Several sources, including the City of Minneapolis Assessor's Office, Hennepin County Assessor's Office and building permit data, City of Saint Paul Property Information Office, and the Saint Paul Port Authority, were consulted to determine or confirm property location, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. Properties for which there were firm specific reuse plans in place were considered as having development under way. This analysis indicated that 37 of the 86 properties have reuse completed or under way and had benefited from assistance from EPA's Brownfields Program. These properties are listed in Exhibit 3-1, and their locations are shown in Exhibit 3-2. Site size ranged from 0.1 acre to 18 acres, with an average of 2.2 acres. Only three sites are greater than five acres. Some of the properties were not completely built out, although development had begun or was ongoing.

Air Quality Impacts and Personal Vehicle Energy Use: Data used to estimate automobile use, personal vehicle energy consumption, and air pollutant emissions, as well as measures of urban form, were provided by the Metropolitan Council, which coordinates economic development, provides planning assistance to communities, and provides transit, wastewater, and other services for the seven-county Minneapolis-Saint Paul region. The counties include Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington (Exhibit 3-3). For planning purposes, the Council subdivides the region into 1,201 traffic analysis zones (TAZs) of varying size.

Estimates of environmental and urban form indicators were developed for each of the TAZs in which the brownfields are located. Some of these indicators were scored directly from the regional transportation demand model by the Metropolitan Council staff, while others were estimated by the study team based on data from the region's model. For example, the personal vehicle energy use and pollutant emissions were estimated based on vehicle miles traveled (VMT) and vehicle trips (VT) data provided by the Council. Open space connectivity was calculated using INDEX planning software, and the accessibility indicators were provided by the Council.

Exhibit 3-1. Minneapolis-Saint Paul Brownfield Properties Studied

Site No.	Property Name	Address	City	Parcel Size (Acres)	Bldg Size (SF)	Past Use	Current Use	Future Use
1	Mel Schroeder Inc.	One Malcolm Avenue SE	Mnpl.	0.89	17,097	Commercial	Commercial	Commercial, Apropos studio
2	Tapestry Folk Dance Center	3748 Minnehana Avenue S.	Mnpl.	0.20	10,694	Commercial	Folk dance center	No change expected
3	Former B. F. Nelson	401 North Main Street NE	Mnpl.	0.25	2,532	Residential	Residential	Residential
4	Mandile Fruit Co & Packaging Concepts, Inc.	260 Fremont Avenue N.	Mnpl.	0.58	10,500	IWS warehouse	IWS warehouse	No change expected
5	Hamma	1209 Glenwood Avenue N.	Mnpl.	0.81	7,557	I2-medium industrial district	I2-medium industrial district	Restaurant
6	Minneapolis Builders Exch & Hmong American	1121/1123 Glenwood Avenue N.	Mnpl.	0.84	8,036	Office	Office	No change expected
7	Minneapolis Public School Board of Ed.	1001 Second Avenue N.	Mnpl.	13.60	144,000	Industrial	Industrial	COW warehouse & offices, Board of Ed.
8	KDS, INC	241 Fremont Avenue N.	Mnpl.	1.23	26,160	Vacant warehouse	Occupied warehouse	Warehouse, occupied
9	Timberland Lumber Co, Inc.	250 Fremont Avenue N.	Mnpl.	4.04	10,000	Industrial	Industrial	Lumber co. warehouse, off & storage
10	Northwestern Tire and Auto Co.	1200 Glenwood Avenue N.	Mnpl.	0.41	8,300	Motor vehicle repair; garage	Motor vehicle repair; garage	No change expected
11	MN Plating Facility	1900 Central Avenue NE	Mnpl.	0.87	NA	NA	58 apartment & retail; Silver Angel Secondhand Goods B; Anytime Fitness	No change expected
12	East River Mews, LLC	825 Thornton Avenue	Mnpl.	4.60	NA	Vacant lot; former Superfund site; fuel tank storage	53 condominium units	No change expected
13	Fritz's Auto Service	2800 Bloomington Avenue S.	Mnpl.	0.36	NA	Commercial, auto repair	15 townhouses	No change expected
14	ADM Grain Elevator/ Soo Line Garden	2845 Garfield Avenue S.	Mnpl.	0.96	NA	Light industrial	Community gardens (zoned commercial)	No change expected

Exhibit 3-1. Minneapolis-Saint Paul Brownfield Properties Studied (Continued)

Site No.	Property Name	Address	City	Parcel Size (Acres)	Bldg Size (SF)	Past Use	Current Use	Future Use
15	Former Roofing Company	3408 Snelling Avenue S.	Mnpl.	0.14	NA	Equip. storage / vacant lot	Equip storage/ vacant lot	1 Habitat House
16	Despatch Laundry	113-115 26th Street E.	Mnpl.	0.67	NA	Garage stall	Garage stall	22 dwelling units; with commercial on ground floor
17	2826 Stevens Ave. S.	2826 Stevens Avenue S.	Mnpl.	0.18	NA	Vacant	One house	1 House
18	3408 Snelling Property	3408 Snelling	Mnpl.	0.14	NA	Vacant lot	Vacant lot	1 House
19	2309 Plymouth	2309 Plymouth Avenue N.	Mnpl.	0.23	NA	Former church	Former church	Multifamily residential; 6 units
20	Minneapolis American Indian Center, Inc.	1530 E. Franklin Avenue	Mnpl.	2.52	NA	American Indian Center	American Indian Center; education & community services	No change expected
21	727 5th Ave. S.	727 5th Avenue S.	Mnpl.	0.28	55,415	Apartment building;	Apartment building; 51 efficiencies; 18 1-bedrooms; tot=69	Affordable rental housing in same building
22	1132 South 8th Street	1132 South 8th Street	Mnpl.	0.72	23,792	A16 Apartment	Apartment 56 efficiencies, 1- one bedroom; 57 units; 2-stories	Affordable rental housing
23	1515 Chicago Avenue	1515 Chicago Avenue	Mnpl.	0.75	15,096	Apartment building	Affordable rental housing; 38 efficiencies in same building	No change expected
24	3254 Stinson Blvd.	3254 Stinson Blvd.	Mnpl.	0.97	NA	Former gas station and car repair shop	Former gas station and car repair shop	2 Houses
25	271 Girard	271 Girard	Mnpl.	0.11	NA	Vacant lot	Vacant lot	1 House
26	Office Warehouse Building	867-885 Pierce Butler Route	St. Paul	2.17	52,963	Office & warehouse; Building 1966	Office & warehouse	Office & warehouse
27	Case Distribution	1927 Case Avenue	St. Paul	18.00	NA	Warehouse	Warehouse	Storage + low-rise office
28	Twin City Castings	750 Pelham Blvd.	St. Paul	0.52	NA	Vacant commercial bldg	Vacant commercial bldg.	Commercial: New Bldg built 2005
29	Como Avenue commercial property	SW of Western Avenue and Como Avenue	St. Paul	2.70	NA	Auto salvage yard	Auto salvage yard	No change expected

Exhibit 3-1. Minneapolis-Saint Paul Brownfield Properties Studied (Continued)

Site No.	Property Name	Address	City	Parcel Size (Acres)	Bldg Size (SF)	Past Use	Current Use	Future Use
30	Whirlpool Building 17	844 Arcade Street	St. Paul	4	NA	Commercial bldg	Indoor/outdoor rock climbing facility	No change expected
31	Mississippi and Hyacinth	NE of Mississippi Street and Hyacinth Avenue	St. Paul	1.3	NA	Vacant lot	Vacant lot	10 houses
32	Nebraska Ave E. & Arkwright St. (lots 13, 14, 15, & 16)	Vacant parcels on Nebraska/ West of Arkwright	St. Paul	0.4	NA	Vacant lot	Vacant lot	3 houses
33	962 Forest Street	962 Forest Street	St. Paul	0.1	5,040	Retail (1-story)	Retail (1-story)	No change expected
34	Crane-Ordway Building	281 East 5th Street	St. Paul	0.22	64,960	Vacant commercial building	Vacant commercial building	Building converted to 70 affordable rental and for-sale units
35	Dale Street Shops Wt	500 Minnehaha Avenue W.	St. Paul	6.7	NA	Vacant lot	Vacant lot	Commercial/light Industrial/ mixed
36	Dale Street Shops - East	500 Minnehaha Avenue W.	St. Paul	4.5	NA	Vacant lot	Vacant lot	Commercial/light industrial/ mixed
37	Hmong American Funeral Home/Riverview Industrial park Parcel E-3	NE of Eaton Street and West Lafayette Frontage Road	St. Paul	3.3	120,000	Vacant lot	Vacant lot	Office/flex

Exhibit 3-2. Locations of 37 Brownfield Sites in Minneapolis and Saint Paul

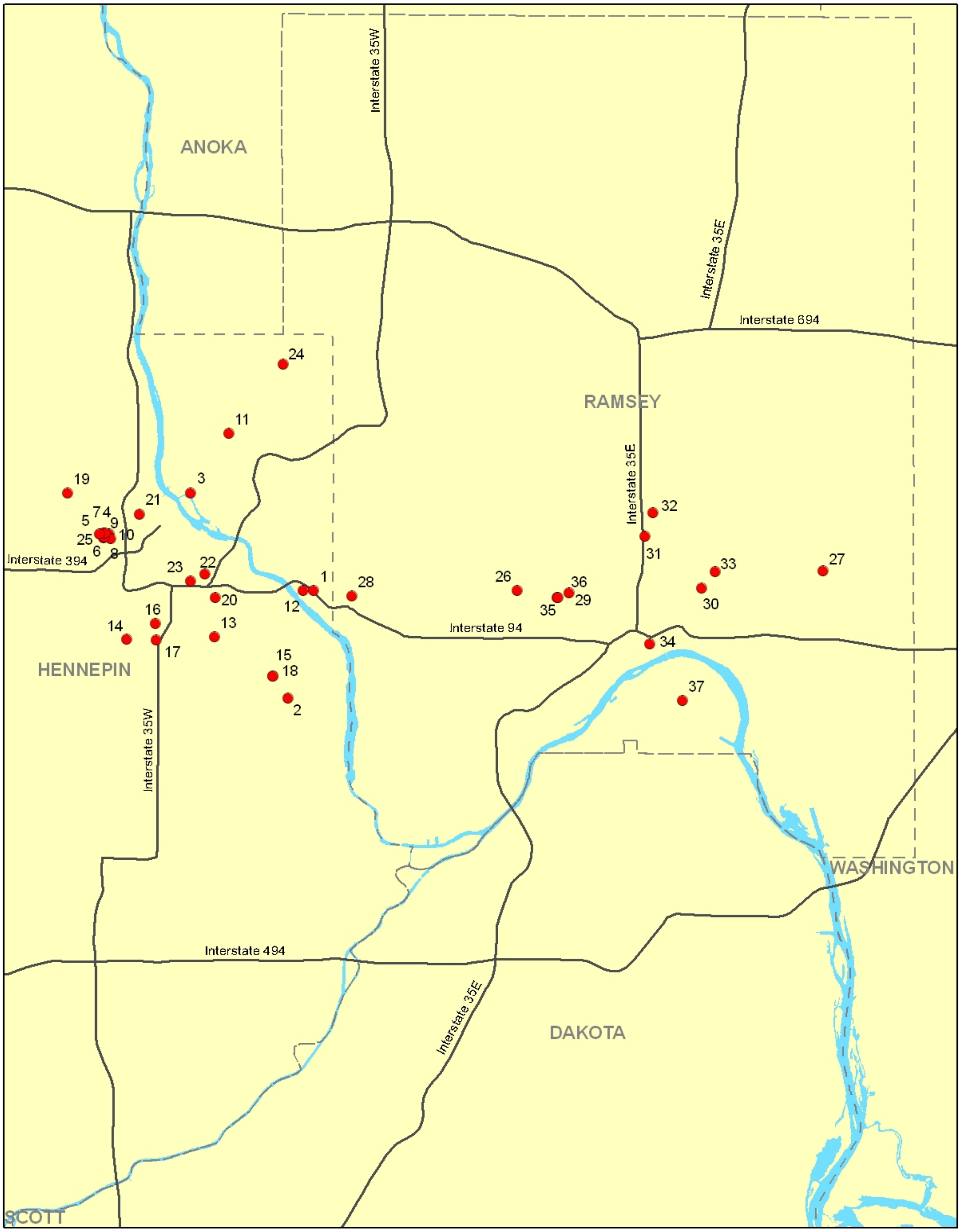
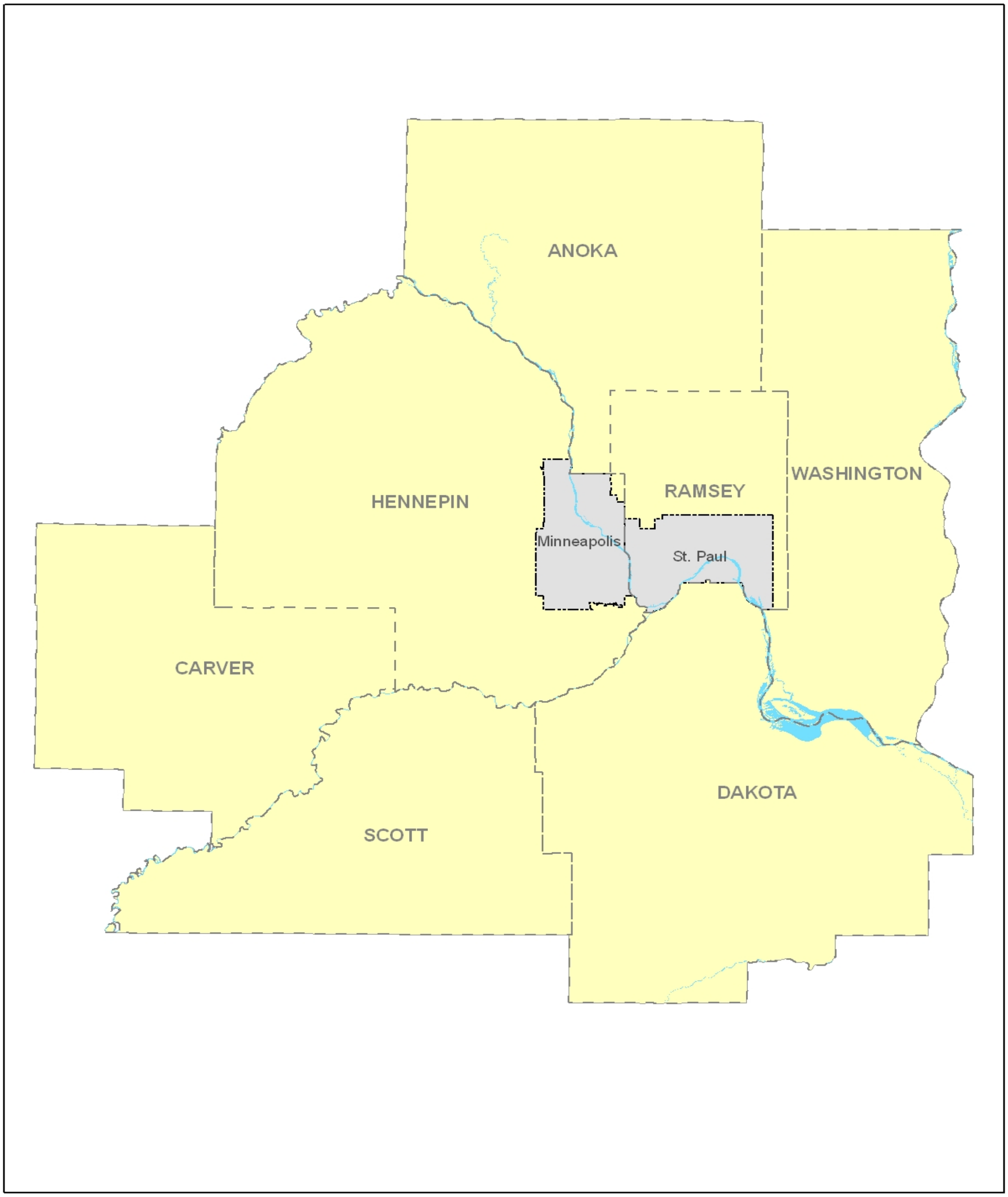


Exhibit 3-3. Metropolitan Council Planning Area



Water Quality Impacts: The Long-Term Hydrologic Impact Assessment (L-THIA) watershed management model was used to estimate stormwater runoff and pollutant loads for each site. The model calculates runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. L-THIA contains data on average county precipitation, generally accepted soil curves for each type of land use (USDA 1986), and, when available, hydrologic soil group. Data on site location, site size, and land use type (Exhibit 3-1) were entered into the model. Soil groups were derived from USDA's soil survey data and entered into the model. Appendix B describes the rationale for using this model, how it was applied, and some important assumptions and limitations.

It was assumed that all soil at the brownfield sites within the Twin Cities was type B. This data was not available from USDA. This assumption is based on data from about 10 sites in Hennepin County. About two-thirds of the acreage of these sites contains B soils. Soil types for the alternative locations were drawn from USDA's Soil Survey Data (USDA 2008, 2009), since L-THIA's soil-type feature was not functioning. The effect of these assumptions on the overall conclusions is likely to be small.

The estimated stormwater runoff from redeveloped brownfields in the Twin Cities is approximately 0.6% greater than that from the former uses.

3.2 Alternative Conventional Development Scenario

The alternative conventional development scenario assigned locations that were reasonable for the same type of development if the development had not been built on the brownfields, and estimated the environmental performance of these locations.

Alternative Conventional Locations: For each brownfield site, an alternative location was assigned based on recent development patterns in the region. Since the brownfield sites in this dataset are only a small portion of total development in the region, it is reasonable to assume that the alternative development would generally follow the prevailing patterns. Using the process outlined in Appendix B, Methodology, the counterpart for each brownfield site was selected from one of the top 10% highest growth employment and residential areas (117 TAZs).[6] The fastest growing TAZs were based on population and employment shifts from 1995 to 2005 where the percentage of the regional population and employment for each TAZ experienced the greatest increase in population and employment with respect to all other TAZs.[7] This period is believed to overlap with much of the development activity, although the dates of development activity at many of the sites could not be precisely identified. The high-growth areas are shown in Exhibit 3-4. Alternative locations for each of the 37 brownfield sites are shown in Exhibit 3-5.

Alternative Conventional Development Size: Development generally consumes more acreage per capita in suburban and rural areas than in more dense, urban areas, due to building practices, parking requirements, and typically lower land cost. Based on a range of values derived from literature on land use patterns (Appendix B), it was assumed that the conventional/greenfield sites would generally require an average of two to four times the acreage of their brownfield counterparts. Land use decisions are inherently influenced by a number of site-specific factors. As a result, there is wide variation in the amount of land consumed by similar uses in different areas, or even between

[6] In order to select the fastest growing TAZs between 1995 and 2005, the 1990 TAZ boundaries were used. Since there were 1,171 TAZs in 1990, there are 117 TAZs in the top 10%.

[7] To reflect growth in both employment and residents, the 37 brownfield sites were divided into two groups according to whether, based on their redevelopment use, they were more likely to be located in, or economically linked to, a residential area (19 sites) or a non-residential area (18 sites).

properties within close proximity. Land use can be determined by overlapping jurisdictions, special exemptions, historical practices, and other factors that may cause developers to over- or under-comply with zoning densities. An average acreage multiplier of two is used for a more conservative estimate, and an average of four is used for an upper bound.

Air Quality, Energy Consumption, and Urban Form: Using information on the alternative locations, acreage, and types of use, the environmental characteristics of these locations were described according to indicators scored from the data in the transportation demand model, in a procedure identical to that described previously for the brownfield sites.

Water Quality: Using information on the alternative locations, which were assumed to be greenfields for the stormwater modeling, acreage, and types of use, the stormwater runoff and pollutant loads from these locations were estimated with the L-THIA model in a procedure identical to that described previously for the brownfield sites.

It was assumed that the development would take place either in a former vacant pasture area or in a former agricultural area.[8] Using two land use categories provides a range of acceptable values rather than a single estimate. This approach is appropriate, as the precise location of the greenfield site within the TAZ or census tract is unknown. To obtain the net new runoff contribution of the greenfield development, the existing runoff (pasture or agricultural area footprint) was subtracted from the runoff expected from the developed uses, which were primarily commercial and residential. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites were also factored in. These calculations are described in greater detail in Appendix B.

3.3 Comparison of Brownfield and Conventional Scenarios

For each site pair, the estimated indicators were compared, and totals for all sites were averaged. The results of the air quality and energy analysis were generally expressed in terms of percent difference in VMT and emissions associated with the brownfield site compared to its conventional alternative on a per capita basis. The results of the stormwater runoff analysis were expressed in terms of percent difference in stormwater runoff and pollutants from brownfields in the group of 37 site pairs. A number of limitations and caveats apply to this comparison. These are discussed in Appendix B, Methodology.

[8] The predominant land uses in the region are agricultural, range, and open land. It is sometimes difficult to distinguish among these uses from satellite images available on Google Earth. L-THIA' Basic module offers three land use categories: forest, pasture/grassland, and agricultural.

Exhibit 3-4. High Growth TAZs in the Minneapolis-Saint Paul Area

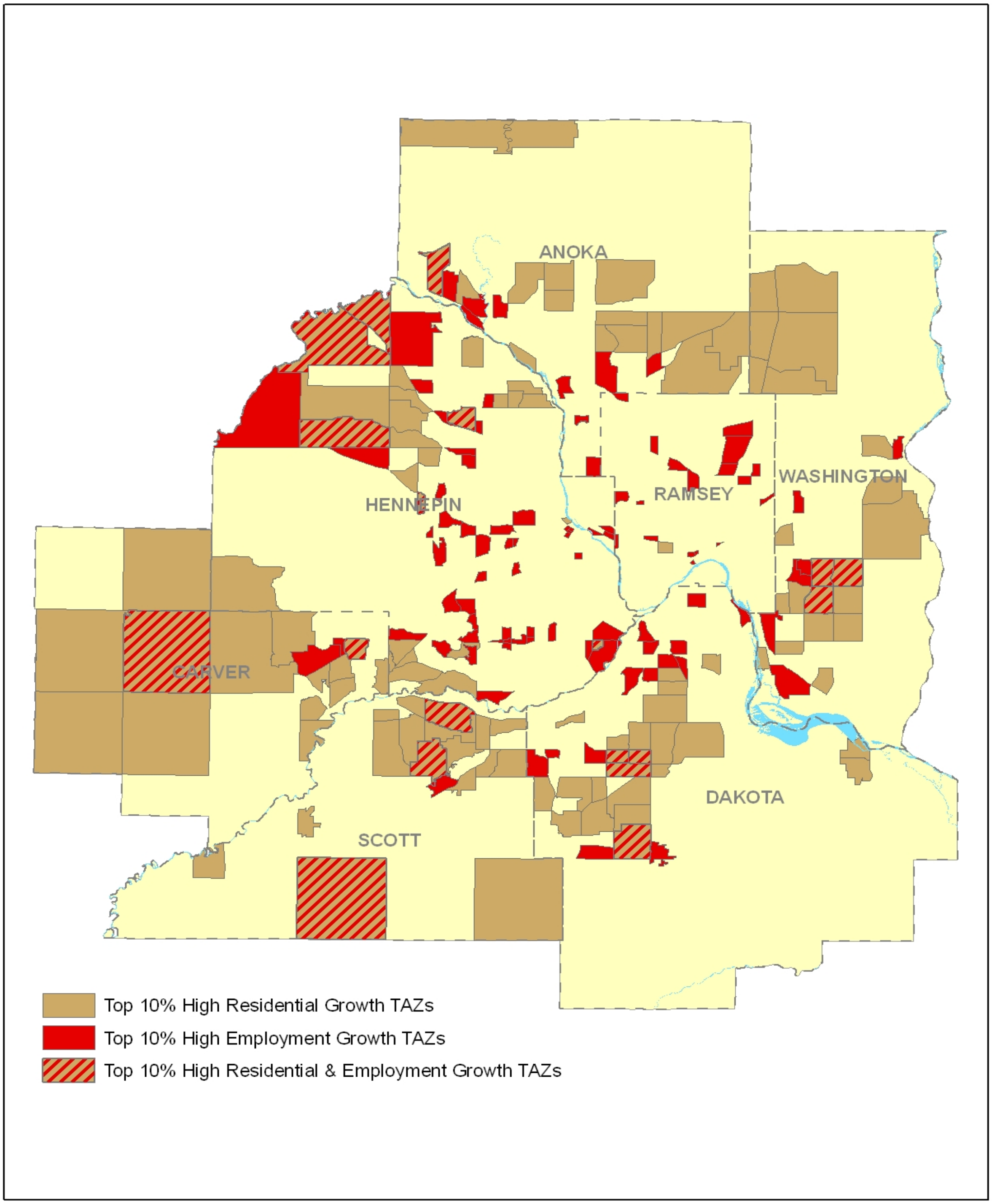


Exhibit 3-5. Alternative Conventional Locations in the Minneapolis-Saint Paul Area: 37 Sites

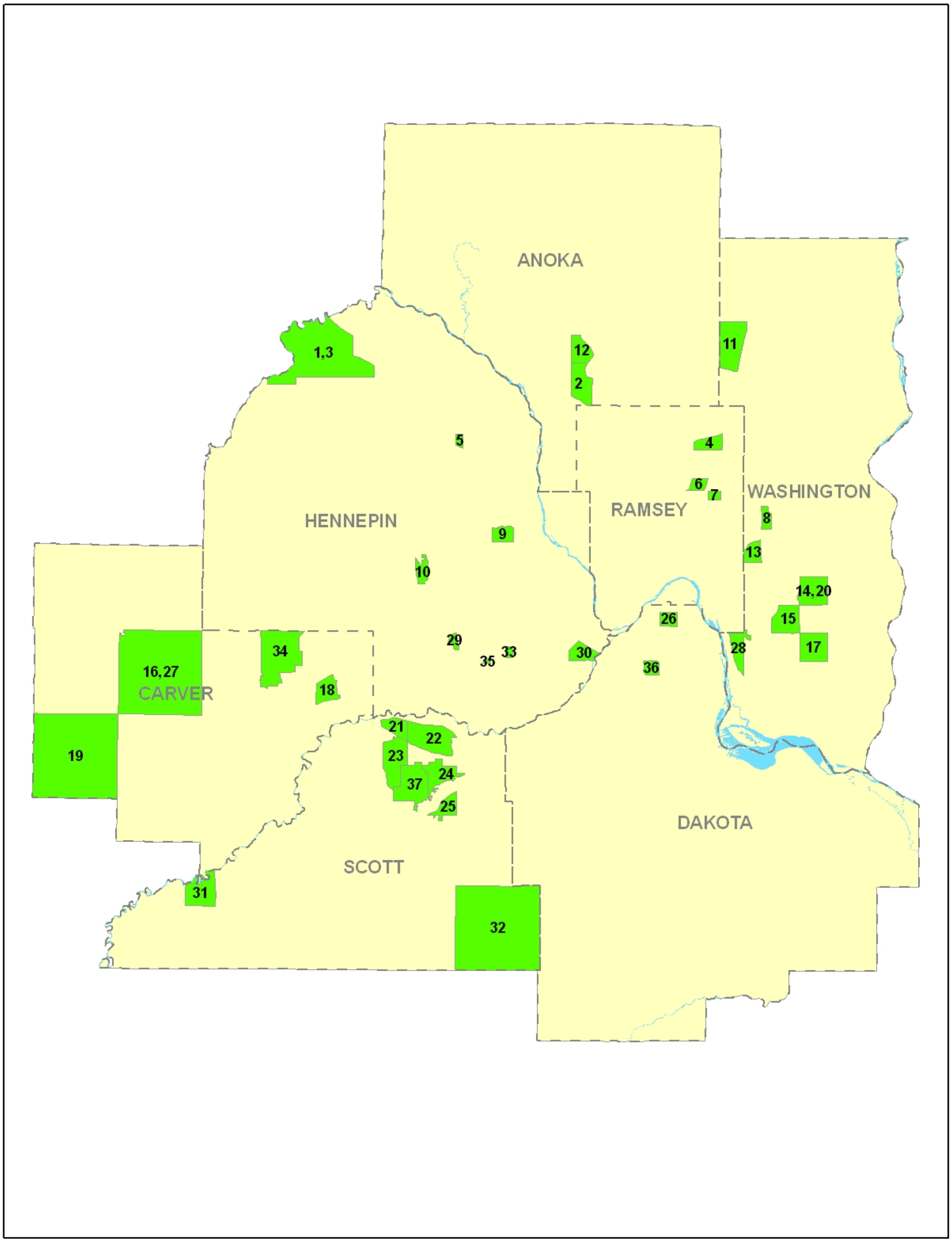


Exhibit 3-6 compares the average differences in the estimated indicators. Twenty-six of the indicators relate to urban form, travel, personal vehicle energy use and air emissions; and 16 variables address land use, stormwater runoff, and water pollutants. In general, the brownfield locations demonstrate substantially greater land-use efficiency, less auto dependency, greater location efficiency, and lower personal vehicle energy use, air pollutant emissions, and stormwater runoff and pollutant loads.

3.3.1 Air Emissions and Personal Vehicle Energy Use

The average brownfield scores were positive for all air emissions and energy use indicators. The results show that nearly all redeveloped brownfield sites result in significantly better environmental performance than similar conventional development.

- Brownfield sites accommodated the same number of homes and businesses on about one-fourth to one-half the land typically used at corresponding conventional sites.
- Automobile use by residents and employees at brownfield locations is estimated to be substantially lower than at the alternative locations.
    - Average daily vehicle miles traveled per capita would be 32% lower.
    - Average daily vehicle trips per capita would be 16% lower.
    - Personal vehicle energy use per capita would be 32% lower.
- The brownfield redevelopment areas average 32% lower carbon dioxide and air pollutant emissions per resident from personal vehicle use relative to conventional development.

The positive environmental indicator values at the brownfield locations stems from the fact that the brownfield neighborhoods in this study are denser and more accessible by most measures. Density is measured primarily by the number of residents, households, or employees per gross acre. Generally, the denser an area, the shorter the distance to various destinations for purposes such as shopping, recreation, and employment. Population density for the average brownfield TAZ in this study is about six times that of the average alternative TAZ. Employment density in the average brownfield TAZ is nearly three times that of the average alternative TAZ.

Accessibility is measured primarily in terms of time required to travel between key origin-destination points within the region. Based on the indicators in Exhibit 3-6, people living and working in the brownfield neighborhoods have substantially better accessibility to other neighborhoods and to points within their TAZs than those in their conventional counterparts. Accessibility to transit shows the greatest difference, although walking and automobile travel also show substantial differences. For example, 1.6% of all employees in the seven-county region are within a 30-minute transit ride to the center of the average brownfield TAZ. The figure for conventional TAZs is 0.02%. For households, the figures are 5.1% and 0.05%, respectively.

Exhibit 3-6. Comparison of Environmental Indicators in the Minneapolis-Saint Paul Area: Average Differences Between 37 Site Pairs

		Brownfield Average	Conventional Average	Percent Change (Conventional-Brownfield) (a)
Accessibility Indicators				
Households (HH) in TAZ		1,545	1,418	9%
% total region households within 10 min. walk from TAZ center		0.11%	0.06%	75%
% total region households w/in 30 min. transit ride from TAZ		5.12%	0.05%	9,470%
% total region households w/in 6 mi. by SOV from TAZ center		20.30%	3.54%	474%
Employment in TAZ		2,069	3,140	34%
% total region employees within 10 min. walk from TAZ center		0.12%	0.03%	309%
a% total region employees within 30 min. transit ride from TAZ		1.62%	0.02%	10,409%
% total region employees within 6 mi. by SOV from TAZ center		15.02%	3.37%	346%
Environmental Performance Indicators	**Units**			
Population density	persons/gross acre	12.86	2.08	519%
Dwelling density	DU/gross acre	5.1	0.93	450%
Transit adjacency to housing	% pop. w/in 1/4-mi.	90.47	26.19	245%
Jobs-to-housing balance	jobs/dwelling unit	1.34	2.21	40.0
Employment density	emps/gross acre	13.82	5.00	176%
Transit adjacency to employment	% empl. w/in 1/4-mi.	90.47	25.94	249%
Open space connectivity	0-1 scale	0.05	0.19	73%
Nitrogen oxides (NOx) emissions	lbs/resident/yr.	27.32	40.82	32%
Carbon dioxide emissions (CO_2)	lbs/resident/yr.	5,067	7,571	32%
Hydrocarbon (HC) emissions	lbs/resident/yr.	53.03	79.24	32%
Carbon monoxide (CO) emissions	lbs/resident/yr.	409.82	612.28	32%
Home-based vehicle miles traveled	mi/capita/day	13.79	20.24	32%
Non-home-based vehicle miles traveled	mi/capita/day	6.18	9.60	34%
Total vehicle miles traveled	mi/capita/day	19.97	29.84	32%
Home-based vehicle trips	trip/capita/day	1.57	1.81	13%
Non-home-based vehicle trips	trip/capita/day	0.86	1.09	19%
Total vehicle trips	trip/capita/day	2.42	2.89	16%
Personal vehicle energy use	MMBtu/capita/yr.	45.56	67.5	32%
Stormwater Runoff and Pollution Indicators (Total for All 37 Site Pairs)	**Percent Change (Conventional/Greenfield less Brownfield) (a)**			
	Pasture (Grassland)		**Agricultural Land**	
	Lower Bound (2x Brownfield Acreage)	Upper Bound (4x Brownfield Acreage)	Lower Bound (2x Brownfield Acreage)	Upper Bound (4x Brownfield Acreage)
Land area (acres)	50%	75%	50%	75%
Annual runoff	59%	69%	48%	56%
Nitrogen	65%	75%	-15%	-17%
Phosphorous	68%	81%	-31%	-36%
Suspended solids	71%	83%	26%	30%
Biological oxygen demand	71%	83%	67%	79%
Chemical oxygen demand	71%	84%	71%	84%
Oil and grease	71%	84%	72%	84%
Lead	68%	79%	69%	80%
Copper	64%	74%	70%	79%
Zinc	72%	83%	70%	79%
Cadmium	66%	74%	63%	67%
Chromium	62%	73%	49%	55%
Nickel	71%	83%	71%	81%
Fecal coli	70%	82%	-18%	-21%
Fecal strep	69%	82%	69%	82%

Notes:

TAZ = traffic analysis zone; HH = household; Ac = acre; Pop = population; SOV = single occupancy vehicle; DU = dwelling unit; MMBTU = millions of British thermal units

(a) Percent change calculated as: [(Value for conventional – Value for Brownfield) / Value for conventional] x 100.

The primary air quality indicators in this study are emissions per resident of nitrogen oxides, carbon dioxide, carbon monoxide, and hydrocarbons. Lower emissions are considered a positive environmental outcome, and more intensive development in more central areas usually results in lower emissions than the same amount of development in less dense areas that are less accessible. However, although total emissions in a region may be at acceptable levels, a particular intensive development can result in local "hot spots" of one or more pollutants. Hot spots are local areas of very high concentrations that may present a health or environmental risk or cause an area to fall out of compliance with air pollutant levels.

Some emissions, such as carbon monoxide, are primarily a local health concern. Others, such as carbon dioxide, are greenhouse gases, which contribute to climate change. Some pollutants, such as nitrous oxide, can have local health impacts and are also greenhouse gases. None of the brownfield development projects in the Twin Cities is large enough or has enough industrial or transportation activity to be a regional concern on its own. However, analysis of other development in the area was not conducted to see if, combined with the other projects, there might be significantly elevated levels of emissions.

3.3.2 Stormwater Runoff and Pollutant Loads

Total runoff in the region in would be 59 - 69% lower if development occured on brownfields rather than pasture areas, while it would be 48 - 56% lower for alternative sites on agricultural land (Exhibit 3-6). Compared to pasture areas, percentage reductions for all pollutants are substantial. Loads of conventional pollutants, such as nitrogen, phosphorous, suspended solids, and biological oxygen demand would be 65% to 84% lower. Metals ranged from 62% to 83%. Compared to agricultural areas, the loadings of three pollutants, nitrogen, phosphorous, and fecal coli, would increase if the brownfield were developed in lieu of the greenfield (15-17%, 31-36%, and 18-21%, respectively). Agricultural land has high concentrations of these substances and, under the brownfield redevelopment scenario, they would continue to generate stormwater runoff. Loads of other conventional pollutants ranged from 26 to 84% lower and metals ranged from 49 to 81% lower.

Based on the calculations using L-THIA, stormwater runoff from the brownfield sites will change minimally from pre- to post-development. Runoff from redeveloped brownfields is estimated to be only about 0.6% lower than that from former uses within the Twin Cities. This result is attributable to the fact that some properties will continue in the same land use while others will shift within a developed land use category or among developed categories. The change in runoff across these land uses is a fraction of the values experienced when undeveloped land becomes developed. However, it is unclear how much runoff would actually change, because developers may incorporate more effective stormwater management practices than was the practice at the time of the former property use.

In a separate calculation, runoff was estimated at the alternative locations with and without development, without considering runoff at the brownfield sites. If left undeveloped, the 37 alternative locations in the Minneapolis region would have 67 - 82% less runoff than if they were developed.

Appendix B describes the rationale for using L-THIA, how it was applied, and some important assumptions and limitations of this analysis.

4. Emeryville Area

The analysis of the Emeryville, California area follows the basic methodology outlined in Section 1 and described in more detail in Appendix B. It was based on a set of 39 brownfield properties in the City of Emeryville that benefited from U.S. EPA's Brownfields Program funding and had redevelopment completed or under way. These parcels represent a variety of uses and are scattered throughout the small, 1.9-square mile city.

4.1 Brownfield Redevelopment Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in the city, and measures of urban form, energy use, air emissions, and estimated stormwater runoff and pollution loads from the brownfield locations. Energy use was measured in terms of personal vehicle energy use per capita. Urban form indicators included density measures (population, dwelling units, and employment), and several indicators of travel efficiency.

Emeryville Brownfield Properties: Using EPA's ACRES database and information provided by the City of Emeryville Redevelopment Agency, about 60 brownfield properties that had been associated with U.S. EPA grant activities were initially identified in Emeryville. Information from several sources was used to determine or confirm property location, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. These sources included the Emeryville Redevelopment Agency, California Department of Toxic Substances Control, and the Alameda County Assessor's office.

This analysis identified 39 properties that had reuse completed or under way and had benefited from EPA Brownfields Program assistance. Properties for which there were firm, specific reuse plans in place were considered as having development under way. For some properties, it was difficult to confirm that EPA Brownfields funds were involved, because documentation of specific funding sources was sparse, and local officials did not recollect the site-specific situation. The 39 sites are listed in Exhibit 4-1, and their locations are shown in Exhibit 4-2. Site acreage ranged from 0.1 acre to 30 acres. Eight sites are greater than five acres. Some of the properties were not completely built out, although development had occurred or was ongoing.

Air Quality Impacts and Personal Vehicle Energy Use: Data used to estimate automobile use, personal vehicle energy consumption, and air pollutant emissions, and measures of urban form were provided by the Metropolitan Transportation Commission (MTC), the Metropolitan Planning Organization (MPO) for the nine-county area: Alameda, Contra Costa, Marin, Napa, Santa Clara, San Francisco, San Mateo, Solano, and Sonoma (Exhibit 4-3). For planning purposes, the Council subdivides the region into 1,474 transportation analysis zones of varying size.

The environmental and urban form indicators used in this analysis were developed for each of the TAZs in which the brownfields are located. Some of these indicators were scored directly from the regional transportation demand model by MTC, while others were estimated by the study team based on the data from the MPO's transportation demand model. For example, the vehicle energy use and pollutant emissions were estimated based on vehicle miles traveled and vehicle trips data provided by the transportation demand model. The accessibility indicators were also provided by MTC.

Exhibit 4-1. Emeryville Brownfield Properties Studied

Site No.	Parcel ID	Property Name	ADDRESS	Zip CODE	SIZE (acres)	Bldg. Size (SF)	Jobs	Former Use	Current Use	Future Use
1	14241	Breuners/ Ryerson	Hollis Ave. & 65th St.	94608	11	NA	NA	Unknown	Unknown	Mixed
2	14247	E. Baybridge Housing	1325 E. 400th St.	94608	4	NA	NA	Asphalt mixing, metal working, auto repair	Mixed use - shopping center and housing	Same as current, with more density
3	14249	Pixar Animation Studio Office	1200 Park Ave.	94608	13	415K	1,000	Industrial, TSCA landfill	Corp HQ	Same
4	15628	AC Transit	4301 Doyle St.	94608	8.96	NA	NA	Bus depot, manufacturing	Bus depot	Same with more density
5	26821	Dutro	1379 62nd St.	94608	1.28	NA	NA	Light manufacturing - Christy Metal Products (previous owner).	Light manufacturing/hand trucks	Park
6	15627	Jug Liquor	3645 San Pablo Ave.	94608	0.1	2,830	NA	Liquor store, gas station	Liquor store- retail	Retail
7	15625	Viacom Mound	Horton and 59th St.	94608	1.59	NA	NA	Industrial, TSCA landfill	Parking lot	Transit center, pkg. & R&D &/or office &/or medical facilities
8	20221	4062 Hollis	4062 Hollis St.	94608	0.78	NA	NA	World Geodetic System of 1984	Metal stamping, storage	Arts and cultural center
9	65861	4369 Adeline Street - Thamkul	4369 Adeline St.	94608	0.12	NA	NA	Apartment building, with ground floor community use.	Same - helped with transaction	Same
10	27401	Ambassador	1160-1168 36th St.	94608	0.42	NA	NA	Laundry and multi-tenant commercial	Vacant	Multifamily affordable rental
11	20241	Black & White (B&W)	4053 San Pablo Ave.	94608	0.57	NA	NA	Former warehouse and other light industrial uses	Same	Same
12	20201	Ennis/AC Transit	40th and Adeline St.	94608	0.03	NA	NA	Previously owned by Southern Pac. Rail Road, portion of former rail spur	Vacant	Fourplex, relocated from another brownfield site
13	65862	Miller Property	5850 Hollis St.	94608	1.1	NA	NA	Mfg., light industry; adjacent to rail spurs & other brownfields	Light mfg.; & biodiesel pilot manufacturing	Same, with more density
14	12049	Heritage Square	2 Admiral Dr.	94608	3.8	78,513	NA	Offices	Same	Same, with structured parking

Exhibit 4-1. Emeryville Brownfield Properties Studied

Site No.	Parcel ID	Property Name	ADDRESS	Zip CODE	SIZE (acres)	Bldg. Size (SF)	Jobs	Former Use	Current Use	Future Use
15	16160	5701 Hollis	5701 Hollis St.	94608	0.5	NA	NA	Manufacturing/light industrial, chromium plating	Office/retail	Same, with parking converted to park
16	16159	Green City Lofts	1007 41st St.	94608	0.9	NA	NA	Paint manufacturing	62 condos	Same
17	65922	Park Avenue Park - UPRR Parcel D	Sherwin Ave. and Halleck St.	94608	2	NA	NA	Rail yard; owned by railroad co. Adjacent uses are paint/ pesticide manufacture and dry cleaner cartridge recycling	Vacant	Park or exchange the property for equivalent open space on adjacent property
18	86802	1042 48th Street Site	1042 48th St.	94608	0.08	NA	NA	Vacant lot used for a neighborhood garden. A house was razed in 1973. Lead concen-trations above PRGs	Vacant	Community Garden
19	NA	Ikea	4400 Shellmound St.	94608	15.5	275K	300	Steel plant	Vacant	Retail
20	NA	Courtyard by Marriott	5555 Shellmound St.	94608	4.3	162K; 288 rooms,	80	Steel plant	Vacant	Hospitality
21	NA	Gateway Housing	4800 San Pablo Ave.	94608	0.6	17 THs		Gas station	Townhouses	17 townhouses
22	NA	Woodfin Suites Hotel	5800 Shellmound St.	94608	2	177K; 200 rooms	45	Manufacturing	Hotel	Hotel
23	NA	Hollis Business Center	6491 Hollis St.	94608	3.5	225K	NA	Warehouse	Office	Office
24	NA	Remar Lofts (Bakery lofts)	1010 46th St.	94608	1.8	57 HUs	NA	Bakery	Bakery	Residential: Live/work lofts; 57 HUs
25	NA	Emery Station Plaza	59th and Horton St.	94608	12	550K	1270	Tank farm; transformer manufacturing	Mixed use - shopping center and housing	Mixed use - shopping center and housing
26	NA	Emery Tech	6529 Hollis St.	94608	0.35	230K	600	Heavy industry	Office/retail	Office/retail

Exhibit 4-1. Emeryville Brownfield Properties Studied

Site No.	Parcel ID	Property Name	ADDRESS	Zip CODE	SIZE (acres)	Bldg. Size (SF)	Jobs	Former Use	Current Use	Future Use
27	NA	Emeryville Warehouse Lofts	1500 Park Ave (& Hubbard St)	94608	1.7	138 HUs	NA	Warehouse	Residential: 130 lofts, 2 penthouses, 6 townhouses	
28	NA	Oliver Lofts	1200 65th St.	94608	2.85	80K	NA	Oliver Rubber factory	50 HUs	50 HUs
29	NA	Andante Phase 1	1121 40th St.	94608	1.8	15K com. + HU	NA	Card club	Mixed; 102 HU (10 mod, 10 low inc.); 15k sf. com.	Mixed; 102 HU (10 mod, 10 low inc.); 15k sf. com.
30	NA	Bay Street (South Bay front)	5600 Shellmound St.	94608	22	NA	NA	Unknown	Mixed - retail; 400K sf.; 356 HU	Commercial, mixed
31	NA	City Limits	67th St.& Oakland border	94608	30	NA	NA	Fabco auto truck plant	Townhouses	Townhouses
32	NA	Elevation 22	Powell St. between Hollis & Doyle	94608	1.8	71 THs	NA	Industrial & commercial	71 Townhouses	71 Townhouses
33	NA	Liquid Sugar	1251 66th St.	94608	2	54 HUs	NA	Corn syrup processing plant	54 Condos. 1, 2, & 3 BR units	54 Condos. 1, 2, &3 bedroom units
34	NA	Promenade	San Pablo Ave. between Park Ave. and 45th St.	94608	3.2	42K	41	Unknown	Retail	Retail
35	NA	Public Market	5959 Shellmound St.	94608	18	NA	NA	Unknown	Retail	Retail
36	NA	The Courtyards (Ryerson Steel)	65th St. between Hollis and the railroad	94608	5.5	4300 retail & HUs	NA	Ryerson Steel bldg.; warehouse & distribution	331 apartments; 4,300 sf. retail	Same
37	NA	Adeline Place	San Pablo Ave./MacArthur Blvd./Adeline	94608	1.1	30 HUs + retail	NA	Check cashing business	30 HUs + retail	Mixed - 30 HUs + retail
38	NA	Oak Walk (Bay rock)	4002 San Pablo Ave.	94608	1.7	5500 + HUs	NA	Unknown	Mixed: 62 condos & 5500 sf. retail	Same
39	NA	Terraces at Emery Station	5855 Horton St.	94608	1	101 HUs	NA	Unknown	101 apts.	101 apts.

Notes: HU = housing units; TH = town house

Exhibit 4-2. Locations of 39 Brownfield Sites in Emeryville

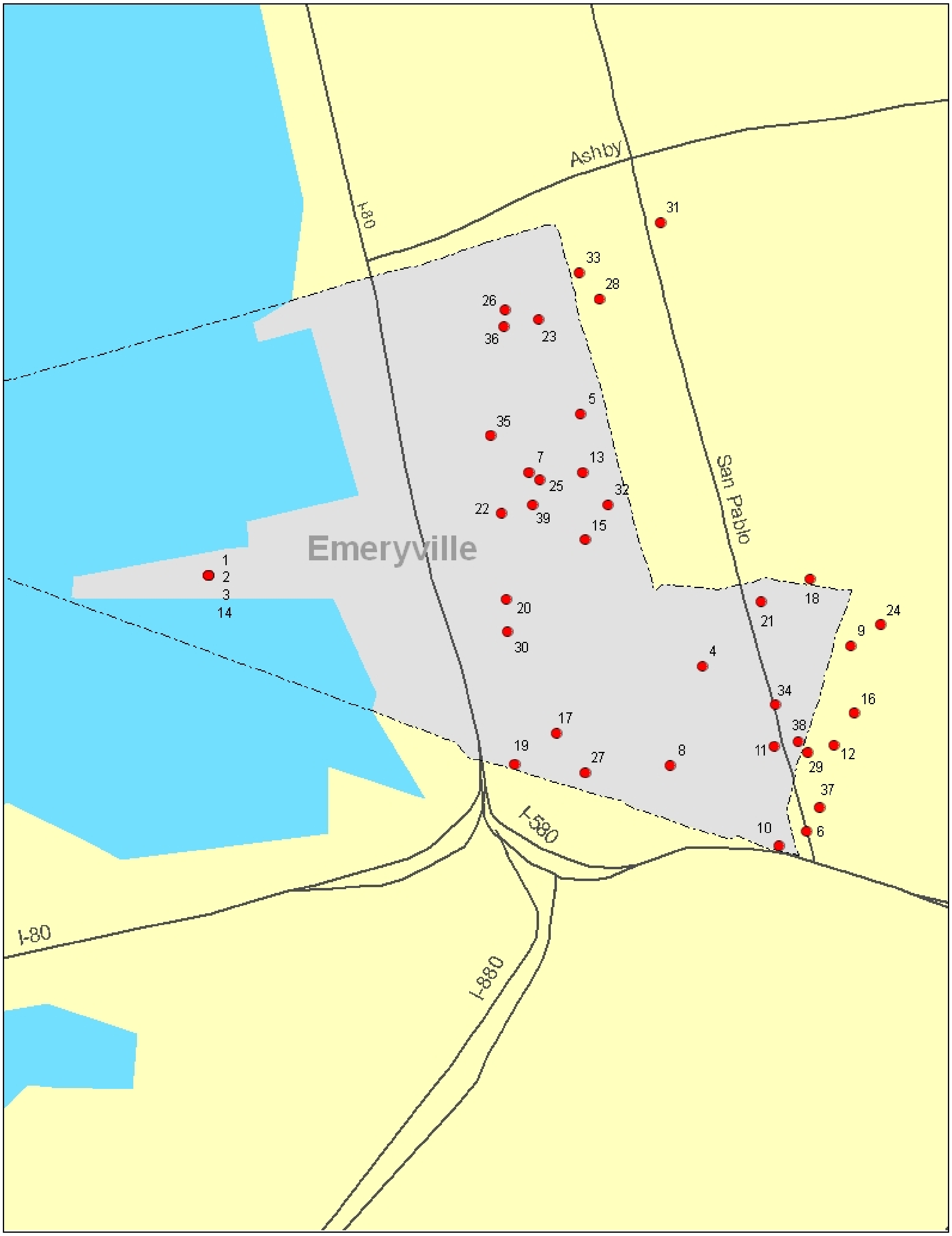


Exhibit 4-3. Metropolitan Transportation Commission Planning Area

Water Quality Impacts: The L-THIA watershed management model was used to estimate stormwater runoff and pollutant loads from each site. The model calculates runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. L-THIA contains data on average county precipitation, generally accepted soil curves for each type of land use and soil type (USDA 1986), and hydrologic soil group. Data on site location, parcel size, and land use type (Exhibit 4-1) were entered into the model. Appendix B describes the rationale for using this model, how it was applied, and some important assumptions.

Several adjustments to the soil-type data were made: (a) The calculations for the Emeryville region were based on 32 sites instead of all 39 in the Emeryville dataset. Seven sites totaling about 30 acres were eliminated because information on hydrologic soil groups was not available for the alternative locations in western Santa Clara County. (b) It was assumed that all soil at the brownfield sites within the City of Emeryville was type D. This assumption is based on the dominance of low permeability soils within two-miles of the city (USDA 2009). This data was not available for the City of Emeryville. Soil types from the remaining alternative locations were drawn from USDA's Soil Survey Data (USDA 2008, 2009) as L-THIA's soil-type feature was not functioning. (c) Where a site's former use was unknown (three sites totaling 32 acres), it was assumed that the future and former uses, and therefore their runoff, were the same. The effect of these assumptions on the overall conclusions is likely to be small.

Based on the calculations using L-THIA, stormwater runoff from redeveloped brownfields in Emeryville is estimated to be about 6.2 % less than that from former uses.

4.2 Alternative Conventional Development Scenario

The alternative conventional scenario assigned locations that were reasonable for the same type and amount of development if development had not been built on the brownfields, and estimated the environmental performance of these locations.

Alternative Conventional Locations: For each brownfield site, an alternative location was assigned based on recent development patterns in the region. Since brownfield sites are only a small portion of total development in the region, it is reasonable that the alternative development would generally follow the prevailing patterns. The development counterpart for each brownfield site was assigned to one of the top 10% highest employment and residential growth locations. The fastest growing TAZs were based on population and employment shifts from 2000 to 2006, where the percentage of the regional population and employment for each TAZ experienced the greatest increase in population and employment with respect to all other TAZs.[9] The high-growth areas are shown in Exhibit 4-4. Alternative locations for each of the 39 brownfield sites are shown in Exhibit 4-5. The use of a statistical site selection procedure minimized any potential partiality that might influence the analysis.

[9] To reflect growth in both employment and residents, the 39 brownfield sites were divided into two groups according to whether, based on their redevelopment use, they are more likely to be located in, or economically linked to, a residential area (19 sites) or a non-residential area (20 sites).

Exhibit 4-4. High Growth TAZs in the Emeryville Planning Area

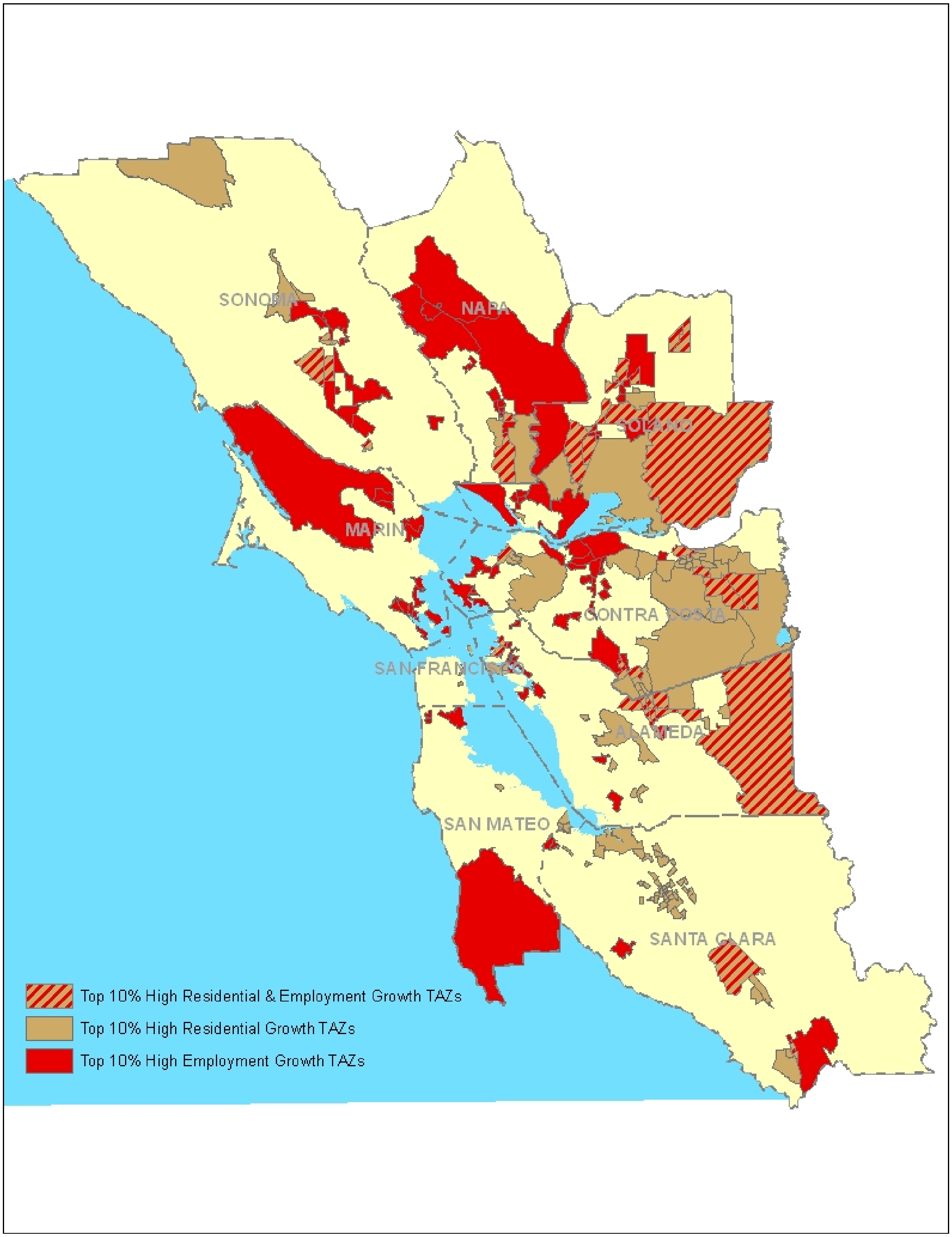


Exhibit 4-5. Alternative Conventional Locations in the Emeryville Area: 39 Sites

Alternative Conventional Development Size: Because development generally consumes more acreage in suburban and rural areas than in more dense, urban areas, it is anticipated that most of the 39 alternative locations would require more land than their brownfield counterparts. Based on a range of values derived from literature on land use patterns (Appendix B), it was assumed that the conventional/greenfield sites would generally require an average of two to four times the acreage of their brownfield counterparts. Land use decisions are inherently influenced by a number of site-specific factors. As a result, there is a wide variation in the amount of land consumed by similar uses in different areas, or even properties within close proximity. Reviewing zoning ordinances will not necessarily result in an accurate estimate of likely land consumption**.** An average acreage multiplier of two is used for a more conservative estimate and an average of four for an upper bound.

Air Quality and Personal Vehicle Energy Consumption and Urban Form: Using information on the conventional locations, acreage, and land use, the environmental characteristics of these locations were described according to indicators scored from the data in the transportation demand model, in a procedure identical to that described above for the brownfield sites.

Water Quality: Using information on the alternative development locations, which were assumed to be greenfields for the stormwater modeling, acreage, and categories of use (e.g., commercial, residential, agricultural), the stormwater runoff and pollutant loads from these locations were estimated with the L-THIA model in a procedure identical to that described above for the brownfield sites.

It was assumed that the new construction would take place either in a former vacant pasture area or in a former agricultural area.[10] Applying two land use categories provides a range of acceptable values rather than a single estimate. This approach is useful, as the precise location of the greenfield site within the TAZ or census tract is unknown. To obtain the net new runoff contribution of the greenfield development, the existing runoff (pasture or agricultural area footprint) was subtracted from the runoff expected from the developed uses, which were primarily commercial and residential. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites were also factored in. These calculations are described in greater detail in Appendix B.

4.3 Comparison of Brownfield and Conventional Scenarios

For each site pair, the estimated indicators were compared, and totals for all sites were averaged (39 for air quality and energy analysis, 32 for stormwater analysis). The results of the air quality and energy analysis were generally expressed in terms of percent difference in VMT and emissions associated with the brownfield site compared to its conventional alternative on a per capita basis. The results of the stormwater runoff analysis were expressed in terms of percent difference in stormwater runoff and pollutants for brownfields in the group of 25 site pairs. A number of limitations and caveats apply to this comparison. These are discussed in Appendix B, Methodology.

The key performance measures are shown in Exhibit 4-6. Twenty-six indicators relate to urban form, travel, energy use and air emissions; and 16 variables address land use, stormwater runoff, and water pollutants. In general, the brownfield locations demonstrate substantially greater land-use and location efficiency; less auto dependency; lower personal vehicle energy use, carbon dioxide and air pollutant emissions per capita; and lower stormwater runoff and pollutant loads for the region.

[10] The predominant uses for undeveloped land in the region are agricultural, range, and open land. It is sometimes difficult to distinguish among these uses from satellite images available on Google Earth. L-THIA' Basic module offers three land use categories for undeveloped land: forest, pasture/grassland, and agricultural.

Exhibit 4-6. Comparison of Environmental Indicators in the Emeryville Area: Average Differences Between 39 Site Pairs

		Brownfield Average	Conventional Average	Percent Change (Conventional less Brownfield) (a)
Accessibility Indicators				
Households (HH) in TAZ		4,299	2,218	94%
% total region households within 10 min. walk from TAZ center		0.22%	0.12%	85%
% total region households w/in 30 min. transit ride from TAZ center		1.38%	0.51%	174%
% total region households w/in 6 mi. by SOV from TAZ center		5.81%	2.87%	102%
Employment in TAZ		16,360	5,062	223%
% total region Employees within 10 min. walk from TAZ center		0.50%	0.25%	97%
% total region Employees within 30 min. transit ride from TAZ center		6.22%	1.06%	485%
% total region Employees within 6 mi. by SOV from TAZ center		6.94%	3.18%	118%
Environmental Performance Indicators	**Units**			
Land area	acres	183	366 - 732	50% to 75%
Population density	persons/gross acre	12.59	8.20	54%
Dwelling density	DU/gross acre	6.60	2.91	127%
Transit adjacency to housing	% pop. w/in 1/4-mi.	100.00	68.84	45%
Jobs-to-housing balance	jobs/dwelling unit	3.81	2.28	67%
Employment density	emps/gross acre	21.95	9.53	130%
Transit adjacency to employment	% empl. w/in 1/4-mi.	100.00	68.84	45%
Nitrogen oxide (NO_X) emissions	lbs/capita/yr.	14.20	28.09	9%
Carbon dioxide (CO_2) emissions	lbs/capita/yr.	2,635	5,210	49%
Hydrocarbon pollutant (HC) emissions	lbs/capita/yr.	27.6	54.50	49%
Carbon monoxide emissions (CO)	lbs/capita/yr.	213.1	421.3	49%
Home-based vehicle miles traveled		5.6	12.0	53%
Non-home-based vehicle miles traveled		4.7	8.6	45%
Total vehicle miles traveled	mi/capita/day	10.4	20.5	49%
Home-based vehicle trips		.8	1.3	36%
Non-home-based vehicle trips		.8	1.3	40%
Total vehicle trips	trip/capita/day	1.6	2.6	38%
Personal vehicle energy use	MMBtu/capita/yr.	23.69	46.84	49%

Stormwater runoff and pollution indicators (Total for all 32 site pairs) (b)	Percent Change (Conventional/Greenfields less Brownfields) (a)			
	Pasture (Grasslands)		Agricultural Lands	
	Low Bound (2x Brownfield Acres)	Upper Bound (4x Brownfield Acres)	Low Bound (2x Brownfield Acres)	Upper Bound (4x Brownfield Acres)
Land area (acres)	50%	75%	50%	75%
Annual runoff	37%	45%	27%	34%
Nitrogen	53%	66%	-61%	-69%
Phosphorous	62%	77%	-100%	-113%
Suspended solids	66%	79%	-8%	-11%
Biological oxygen demand	60%	77%	54%	70%
Chemical oxygen demand	60%	77%	60%	77%
Oil and grease	60%	77%	60%	77%
Lead	55%	66%	62%	74%
Copper	44%	54%	62%	75%
Zinc	69%	80%	66%	77%
Cadmium	54%	55%	48%	48%
Chromium	39%	48%	18%	23%
Nickel	62%	78%	62%	78%
Fecal coli	63%	78%	-38%	-41%
Fecal strep	. 54%	75%	54%`	75%

Notes:

NA: Data not available; DU = dwelling units; MMBTU = millions of British thermal units.

(a) Percentage change calculated as: [(Value for conventional– Value for brownfield) / Value for conventional] x 100

(b) The figures for the stormwater and water pollution variables were based on 32, instead of all 39 sites, because soil type data were not available for part of Sara Clara County.

Appendix B provides further explanation of the methodology used to develop these estimates.

4.3.1 Air Emissions and Personal Vehicle Energy Use

The average brownfield scores were positive for most of the indicators. The calculations show that nearly all (36 out of 39) redeveloped brownfield sites resulted in better environmental performance than similar conventional development. These results indicate the following:

- Brownfield sites accommodated the same number of homes and businesses on about one-fourth to one-half the land typically used at corresponding conventional development.
- Automobile use by residents and employees at brownfield locations is estimated to be substantially lower than at the alternative locations.
    - Average daily vehicle miles traveled per capita would be 49% lower.
    - Average daily vehicle trips per capita would be 38% lower.
    - Personal vehicle energy use per capita would be 49% lower.
- The brownfield redevelopment areas average about 49% lower carbon dioxide emissions per capita relative to conventional development.
- The brownfield redevelopment areas average about 49% lower air pollutant emissions, such as nitrogen oxides and hydrocarbons, per capita relative to conventional development.

The positive environmental indicators at the brownfield locations relate to the fact that the brownfield neighborhoods in this study are denser and more accessible, by most measures. Density is measured primarily by the population, households, and employees per gross acre. Generally, the denser an area, the shorter the distance to various destinations for purposes such as shopping, recreation, and employment. Population per gross acre for the average brownfield TAZ in this study is about is 54% greater than for the average alternative TAZ, and the number of employees per gross acre at the average brownfield location is 2.3 times that of the average alternative TAZ.

Accessibility is measured in terms of the time required to travel between key origin-destination points within the region and distance to transit. Based on the indicators in Exhibit 4-6, people working in the brownfield neighborhoods have better accessibility to other neighborhoods and to points within their TAZs than those in their conventional counterpart areas. For example, 7% of all employees in the region are within six miles, by single-occupancy vehicle, from a TAZ center for the average TAZ where a brownfield is located. The average figure for the conventional counterpart TAZs is 3%. All employees in the region are within ¼ mile of a transit facility in the brownfield TAZs, compared to only 69% for the alternative TAZs. For households, comparison of accessibility and proximity figures also indicates that the brownfield areas generally have better environmental performance than the conventional locations.

The primary air quality indicators in this study are emissions of pollutants per capita, such as nitrogen oxides, carbon dioxide, and carbon monoxide. Lower emissions are considered a positive environmental outcome, and more intensive development in more central areas usually results in lower emissions than the same amount of development in less-dense areas that are less accessible. However, although total emissions in a region may be at acceptable levels, a particular intensive development can result in local “hot spots” of one or more pollutants. Hot spots are local areas of very high concentrations that may present a health or environmental risk or cause an area to fall out of compliance with air quality attainment goals.

None of the brownfield redevelopment projects in Emeryville is large enough, or has enough industrial or transportation activity, to be a regional concern on its own. However, analysis of other development in the area was not conducted to determine if, combined with the other projects, there might be significantly elevated levels of emissions.

4.3.2 Stormwater Runoff and Pollutant Loads

Total runoff in the region in acre feet would be 37 - 45% lower for development on brownfields rather than pasture areas, and 27 - 34% lower than agricultural areas (Exhibit 4-6). Compared to pasture areas, the differences for all pollutants are substantial. Loads of conventional pollutants, such as nitrogen, phosphorous, suspended solids, and biological oxygen demand would be 53% to 79% lower. Metals ranged from 39% to 80% lower. Compared to agricultural areas, the loadings of BOD, COD, oil and grease and fecal strep were at least 70% lower. However, the quantities of four pollutants would increase under the brownfields redevelopment scenario (nitrogen 69%, phosphorous 113%, total SS 11%, and fecal coli 41%). Agricultural land often has high concentrations of these substances and, under the brownfields redevelopment scenario, these locations would continue to generate stormwater runoff. Loads for other conventional pollutants ranged from 54-77% lower and that of metals ranged from 18 to 80% lower. These totals are based on 32 properties, rather than all 39, because soil type data were not available for seven sites in Santa Clara County, where USDA has not completed a soil survey.

Stormwater runoff from redeveloped brownfields is estimated to be about 6% greater than that from former uses within the City of Emeryville. This result is caused by shifts in land use from one type of developed use to another, usually from industrial to commercial or residential. For about half the properties, land use type did not change. Nevertheless, it is unclear how much runoff would actually change because developers may incorporate more effective stormwater management practices than were used at the time of the former property use. Runoff at the alternative locations would be 44 - 58% lower if left undeveloped than if developed.

Appendix B describes the rationale for using this model, how it was applied, and some important assumptions and limitations.

5. Baltimore Area

The analysis of the Baltimore, Maryland area follows the basic methodology outlined in Section 1 and described in more detail in Appendix B. It was based on a set of 37 brownfield properties in the City of Baltimore that benefited from U.S. EPA Brownfields Program funding and had redevelopment completed or underway. These sites represent a variety of uses and are scattered throughout the city.

5.1 Brownfield Redevelopment Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in the city, and measures of urban form, energy use, air emissions, and estimated stormwater runoff and pollution loads from the brownfield locations. Energy use was measured in terms of personal vehicle energy use per capita. Urban form indicators included density measures (population, dwelling units, and employment), and several indicators of travel efficiency.

Baltimore Brownfield Properties: Using EPA's ACRES database, the EPA Region 3 web site, information provided by the Baltimore Development Corporation, and other online sources, 102 brownfield properties in the City of Baltimore were initially identified. For each property, information from several sources, including the Baltimore Development Corporation, Maryland Department of Assessments and Taxation, Maryland Department of the Environment, and the City of Baltimore planning information, was used to determine or confirm property location, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. This analysis identified 37 properties that had reuse completed or under way and benefited from assistance from U.S. EPA's Brownfields Program. Properties for which there were firm, specific reuse plans in place were considered as having development under way. These sites are listed in Exhibit 5-1, and their locations are shown in Exhibit 5-2. Site size ranges from 0.4 to 40 acres, with an average of 8.7 acres. Approximately half the sites have more than five acres.

Air Quality Impacts and Personal Vehicle Energy Use: Data used to estimate automobile use, personal vehicle energy consumption, air pollutant emissions, and measures of urban form, were provided by the Baltimore Metropolitan Council, which is the regional planning organization that undertakes planning activities for the six-jurisdiction area. The Council is involved in a variety of region-wide issues, such as transportation planning, air and water quality programs, and economic and demographic research. A component of the Council, the Baltimore Regional Transportation Board (BRTB) is the federally-recognized Metropolitan Planning Organization (MPO) for the Baltimore region and provides transportation planning and other services for the area. The jurisdictions include the City of Baltimore and the counties of Anne Arundel, Baltimore, Carroll, Harford, and Howard (Exhibit 5-3). For planning purposes, the Council subdivides the region into 1,151 small areas called transportation analysis zones (TAZs) of varying size. These areas are approximately the size of one or more census block groups and often follow census boundaries.

The estimates of environmental and urban form indicators used in this analysis were developed for each of the TAZs in which the brownfields are located. Some of these indicators were scored directly from the regional transportation demand model (TMD) by the Metropolitan Council staff, while others were estimated based on the data from the TMD. For example, the personal vehicle energy use and pollutant emissions were estimated based on vehicle miles traveled (VMT) and vehicle trips (VT) data provided by the Council.

Exhibit 5-1. Baltimore Brownfield Properties Studied

Site No.	Property Name	Address	CITY	Size (Acres)	Bldg. Size (SF)	Jobs	Current Use	Future Use
1	Dickman Street Site (Middle Branch Park)	101 W. Cromwell St.	Balt.	7	NA	40	NA	Aquarium nature & education center/ Park
2	921-979 East Fort Avenue (Maryland White Leadworks]	921-979 East Fort Ave. (Foundry at Fort)	Balt.	2.25	NA	200	Developed as mixed use project	Same: Commercial
3	Tulkoff Warehouse	1200 S. Conkling St.	Balt.	1.4	NA	NA	NA	mixed use
4	Brewers Hill East	3701 Dillon St.	Balt.	3		600	Off & mixed use	Same: use commercial
5	Hiken Brothers Inc.	307 South Eaton St.	Balt.	0.39	16,800	NA	Complex Corp	Industrial
6	Chesapeake Machine Company	210 S. Janney St.	Balt.	0.84	NA	15	Chesapeake Machine	Industrial
7	Clipper Industrial Park	3500 Clipper Rd	Balt.	17	NA	245	240 dwelling units; (No. of lofts & apt.) 80,000 s. f. office & artists studios.	Commercial
8	Gunther/Tulkoff	1101,1211, And 1221 S. Conkling St.	Balt.	15.5	NA	NA	Mixed: office, warehouse, and residential	Commercial
9	Carroll-Camden Area/Warner Street Corridor-Lot 3/Block 840	Warner & Haines St. So. of M&T stadium) **	Balt.	11	NA	1500	500 acre area Gateway So. no dev yet on other parcels	Business park (Gateway South; Commercial
10	Bayview Research Center	4940 Eastern Ave.	Balt.	11	573,000	NA	None	Commercial: Medical services & research

Exhibit 5-1. Baltimore Brownfield Properties Studied (Continued)

Site No.	Property Name	Address	CITY	Size (Acres)	Bldg. Size (SF)	Jobs	Current Use	Future Use
11	1809 Bayard Street	1809 Bayard St.	Balt.	0.8	34,881	NA	Zoned industrial; county use 28,500	Commercial: Tithe Corp.; air conditioner manufacture & repair
12	820 Key Highway	820 Key Highway	Balt.	0.47	NA	NA	American Visionary Art Museum, annex	Same
13	Reisterstown Road Properties	4419-4431 and 4501-4551 Reisterstown Rd.	Balt.	1.58	10,200	NA	Planned senior center	Senior activities center
14	Frankford Gardens Shopping Center	5330 Frankford Ave & 5418 Sinclair Ln.	Balt.	3.48	NA	NA	Retail shopping; older stores (reuse)	Same
15	Cambrex Bioscience Inc. Expansion	5901-6001 Lombard St.	Balt.	13.45	NA	150	Fairly new bldg.	Bio Research; part of Hopkins Med. Center
16	Main Steel	1301 Boyle St.	Balt.	0.96	150,000	NA	1 story commercial bldg.	Same Block 2012, lot 1. Rezoned m3 to B-2-3
17	Durett-Sheppard Property (Steel)	1301 Wicomico St.	Balt.	15.5	401,000	NA	Property on market for mixed use. Part used for steel fabrication.	Industrial warehouse; steel & pipe warehouse & fabricating
18	3500 East Biddle Street	3500 East Biddle St.	Balt.	22.5	NA	80	Industrial	Central garage for City of Balt.
19	4400 Reisterstown Road	4400 Reisterstown Rd.	Balt.	0.75	NA	1157	Burger King	Same
20	5600 Lombard Street	5600 Lombard St.	Balt.	10.7	NA	NA	Container storage near port	Remains container storage

Exhibit 5-1. Baltimore Brownfield Properties Studied (Continued)

Site No.	Property Name	Address	CITY	Size (Acres)	Bldg. Size (SF)	Jobs	Current Use	Future Use
21	Fairfield Mixed II Site	Tate St., North of Chesapeake Ave. & East for Fairfield	Balt.	9	NA	NA	NA	Commercial
22	Fairfield Mixed I Site	Sun St. and Chesapeake Ave.	Balt.	9	NA	NA	NA	Commercial
23	Seton Business Park	Metro Dr.	Balt.	40	NA	NA	Commercial: Advance Bank: Balt. Assoc. for Retarded Citizens, Inc.; 5 sites;	Commercial: complete - Chimes Office park
24	Fort McHenry Shipyard	1201 Wallace St.	Balt.	13.8	300,000	40	Complete -Steinwig import-export (metals)	Warehouse, + outdoor storage etc.
25	CSX; 700 Chesapeake Avenue	700 Chesapeake Ave.	Balt.	6	NA	NA	Unknown	Commercial
26	North Haven Street Site	807 North Haven St.	Balt.	7.6	NA	NA	Unknown	Light industry/ & warehouse
27	Fairfield Homes	Shell Rd and Childs Ave.	Balt.	20	200,000	20	Madison Warehouse & Distribution Center	Unchanged, complete
28	Canton Site/Highland Marine Terminal	South Highland Ave.	Balt.	30	800,000	220	150K sf new + 730k K sf rehabilitation	Commercial, unchanged

Exhibit 5-1. Baltimore Brownfield Properties Studied (Continued)

	Property Name	Address	CITY	Size (Acres)	Bldg. Size (SF)	Jobs	Current Use	Future Use
29	American Can	Boston & Hudson Sts.; (2400 Boston St.)	Balt.	4.3	300,000	800	Mixed - retail, office	Same, complete
30	Camden Crossing/Koppers (Perkin St. site)	Poppleton Ave. & McHenry, Scott, & Clifford Sts.	NA	9.7	NA	NA	Residential- 150 dwelling units/ townhouses	Residential
31	Lancaster Square	1816 Lancaster; 708 South Wolfe	Balt.	2	50,000	100	Mixed - retail, office, res. (10 DUs)	Same, complete
32	801 South Caroline Street	801 South Caroline Street	Balt.	3	NA	320	Office and retail	Same
33	806 Haven St.	806 Haven St.	Balt.	1	NA	NA	City maintenance facility	Same
34	Gunther Brewery	3701 O'Donnell St.	Balt.	9.2	NA	NA	Mixed: residential, warehouse, office	Same
35	900-901 S. Wolfe St.	900-901 S. Wolfe St.	NA	1.1	50,000	NA	Office & retail; 250 dwelling units	Same, 33,000 s. f., complete
36	Guilford Pharmaceuticals	Ft. Holabird Industrial Park, 6611 Tributary St.	Balt.	4.5	73,000	100	Pharmaceuticals	Same, complete
37	Chesapeake Advertising	901 E Fayette St.	Balt.	1.5	41,200	NA	Commercial condominiums	Same

Notes:

Residential = SF = square feet; HU = housing units; TH = town house

Exhibit 5-2. Locations of 37 Brownfield Sites in Baltimore

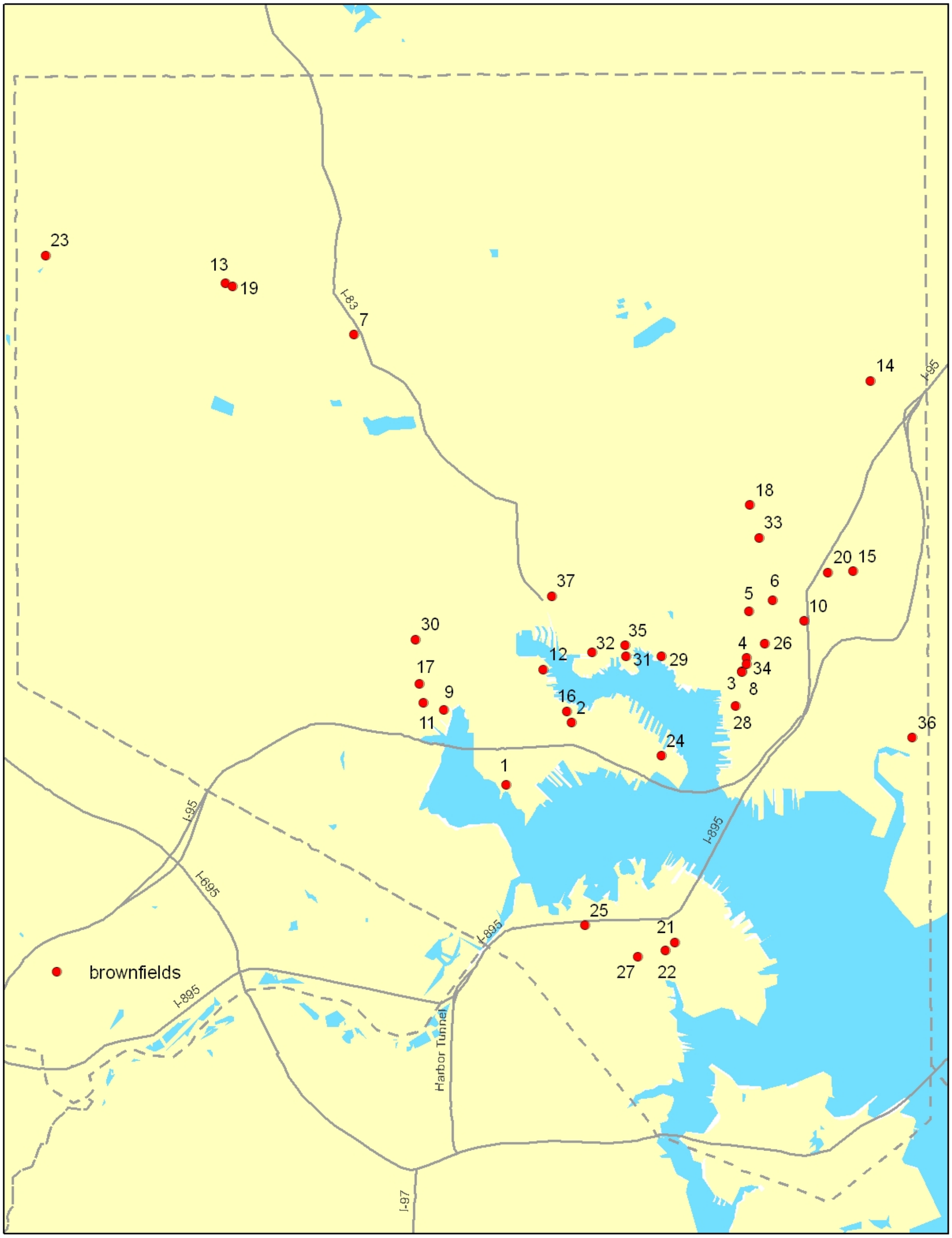


Exhibit 5-3. Baltimore Metropolitan Council Planning Area

Water Quality Impacts: The Long-Term Hydrologic Impact Assessment (L-THIA) watershed management model was used to estimate stormwater runoff and pollutant loads from each site. The model calculates runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. L-THIA contains data on average county precipitation, generally accepted soil curves for each type of land use and soil (USDA 1986), and hydrologic soil group. Data on site location, site size, and land use type (Exhibit 5-1) were entered into the model. Appendix B describes the rationale for using this model, how it was applied, and some important assumptions.

As L-THIA's soil-type feature was not available at the time of the analysis, soil types were drawn from the USDA's on-line soil survey data for the relevant census tracts, except for Baltimore County. The County, which borders the city on the north, east, and west (Exhibit 5-3) is completely separate from the city. Soil type data for Baltimore County was available in a paper version of a 1976 soil survey obtained locally (USDA 1976). For the City of Baltimore, soil type was assumed to be B, based on review of 12 locations in Baltimore County, which indicated that about 88% of soils are group B.

Data on former land uses of the Baltimore brownfield sites was considered unreliable for about three-fourths of the sites. The former land uses for these parcels were assumed equal to the redeveloped uses. This assumption is based on data from the other four cities that indicate that shifting land uses among the brownfield sites within the cities resulted in only small changes in runoff (range of -3.5% to 6.2%, see Exhibit B-7).

5.2 Alternative Conventional Development Scenario

The alternative conventional scenario identified locations that were reasonable for the same type of development if they had not been built on the brownfields, and estimated the environmental performance of these locations.

Alternative Conventional Locations: For each brownfield site, an alternative location was assigned, based on recent development patterns in the region. Since brownfield sites are only a small portion of total development in the region, it is reasonable to assume that the alternative development would generally follow the prevailing patterns. The conventional development counterpart for each brownfield site was assigned to one of the top 10% fastest growing locations (112 TAZs). The fastest growing TAZs were based on population and employment shifts from 1995 to 2005, where the percentage of the regional population and employment for each TAZ experienced the greatest increase in population and employment with respect to all other TAZs. [11] The high-growth areas are shown in Exhibit 5-4. Alternative locations for each of the 37 brownfield sites are shown in Exhibit 5-5. The use of a statistical site selection procedure helped to ensure that the process remained impartial.

Alternative Conventional Development Size: Because development generally consumes more acreage in suburban and rural areas than in more dense, urban areas, it is anticipated that most of the 37 alternative locations would require more land than their brownfield counterparts. Based on a range of values derived from literature on land use patterns (Appendix B), it was assumed that the conventional/greenfield sites would generally require an average of two to four times the acreage of

[11] To reflect growth in both employment and residents, the 37 brownfield sites were divided into two groups according to whether, based on their redevelopment use, they are more likely to be located in, or economically linked to, a residential area (14 sites) or a non-residential area (23 sites).

Exhibit 5-4. High Growth TAZs in the Baltimore Area

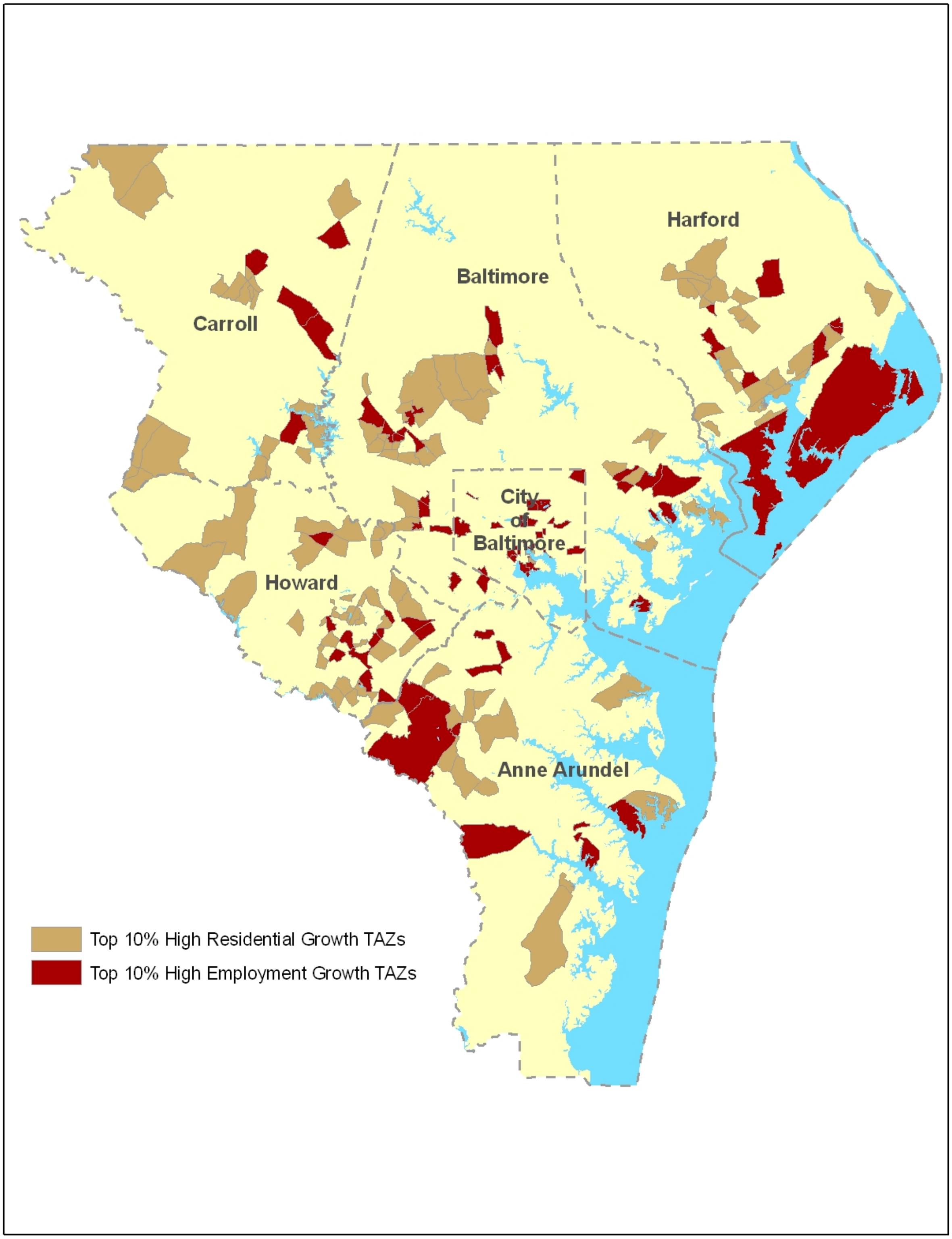
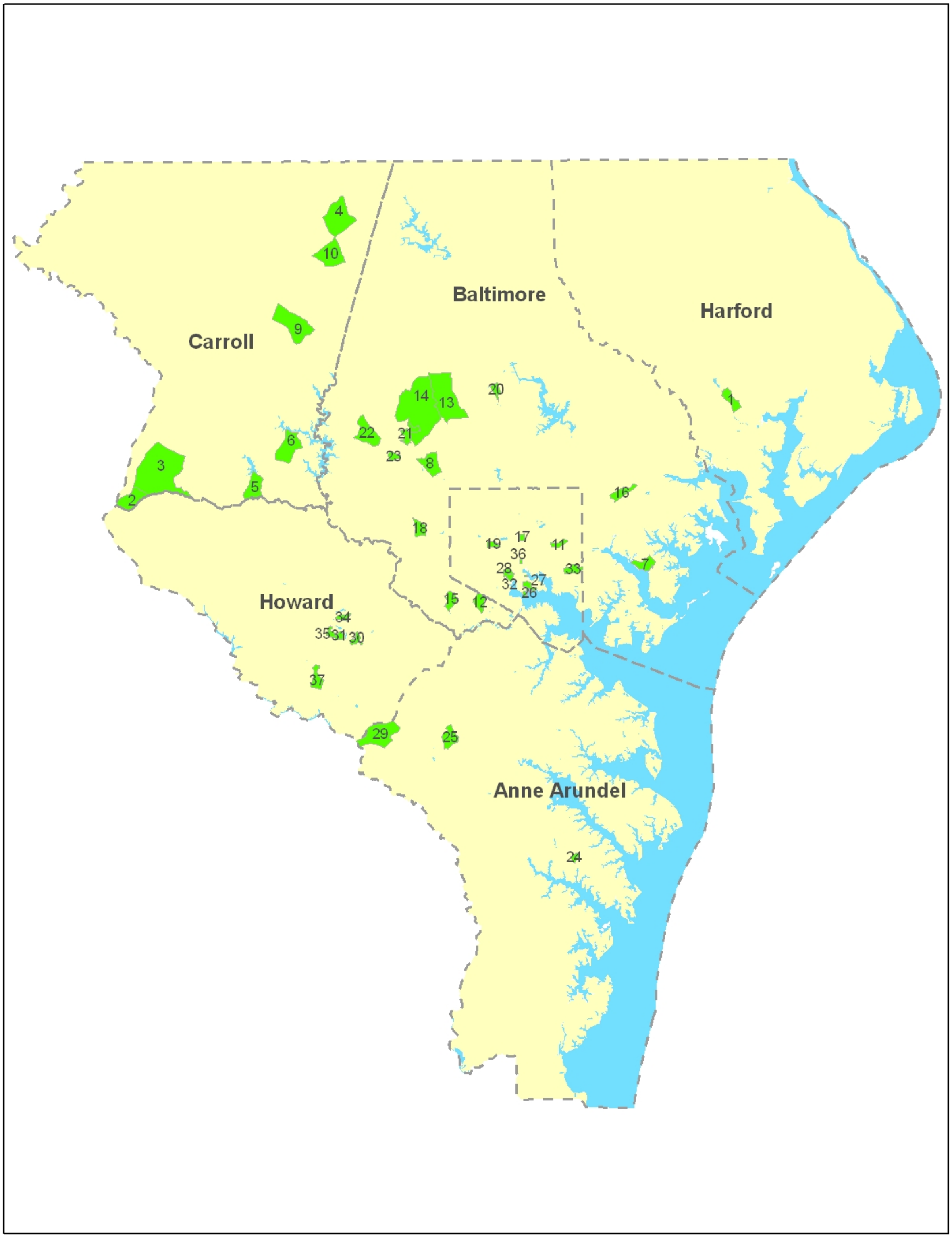


Exhibit 5-5. Alternative Conventional Locations in the Baltimore Area: 37 Sites



their brownfield counterparts. Land use decisions are inherently influenced by a number of site-specific factors. As a result, there is a wide variation in the amount of land consumed by similar uses in different areas, or even within close proximity. Reviewing zoning ordinances will not necessarily result in an accurate estimate of likely land consumption**.** An average acreage multiplier of two is used for a more conservative estimate and an average of four for an upper bound.

Air Quality, Vehicle Energy Consumption and Urban Form: Using information on the conventional development locations, acreage, and categories of use, the environmental characteristics of these locations were described by indicators scored from the data in the transportation demand model using a process identical to that described above for the brownfield sites.

Water Quality: Using information on the conventional development locations, which were assumed to be greenfields for the stormwater modeling, acreage, and categories of use (e.g., commercial, residential, agricultural), the stormwater runoff and pollutant loads from these locations were estimated with the L-THIA model in a procedure identical to that described above for the brownfield sites.

It was assumed that the new construction would take place either in a former vacant pasture area or in a former agricultural area. L-THIA's basic module offers three land use categories for undeveloped land: forest, pasture/grassland, and agricultural. Using two land use categories provides a range of acceptable values rather than a single estimate. This approach is appropriate, as the precise location of the greenfield site within the TAZ or census tract is unknown. To obtain the net new runoff contribution of the greenfield development, the existing runoff (pasture or agricultural area footprint) was subtracted from the runoff expected from the developed uses, which were primarily commercial and industrial. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites were also factored in. These calculations are described in greater detail in Appendix B.

5.3 Comparison of Brownfield and Conventional Scenarios

For each site pair, the estimated indicators were compared, and totals for all sites were averaged. The results of the air quality and energy analysis were generally expressed in terms of percent difference in VMT and emissions associated with the brownfield site compared to its conventional alternative on a per capita basis. The results of the stormwater runoff analysis were expressed in terms of percent difference in stormwater runoff and pollutants for brownfields in the group of 37 site pairs. A number of limitations and caveats apply to this comparison. These are discussed in Appendix B, Methodology.

The key performance measures are shown in Exhibit 5-6. Nineteen of the indicators relate to urban form, travel, personal vehicle energy use, and air emissions; and 16 variables address land use, stormwater runoff, and water pollutants. In general, the brownfield locations demonstrate substantially greater land-use efficiency; less auto dependency; lower personal vehicle energy use, carbon dioxide emissions, and air pollutant emissions per capita; and lower stormwater runoff and pollutant loads for the region. Appendix B discusses a number of caveats that apply to these comparisons.

5.3.1 Air Emissions and Personal Vehicle Energy Use

The average brownfield scores were positive for all indicators. The calculations show that nearly all redeveloped brownfield sites result in substantially better environmental performance than similar conventional development. The key performance measures are shown in Exhibit 5-6.

Exhibit 5-6. Comparison of Environmental Indicators in the Baltimore Area: Average Differences Between Site Pairs

		Brownfield Average	Conventional Average	Percent Change (Conventional less Brownfield) (a)
Accessibility Indicators				
Households (HH) in TAZ		841	871	3%
% total region households w/in 30 min. transit ride from TAZ center		2.98%	1.34%	122%
% total region households w/in 6 mi. by SOV from TAZ center		17.87%	8.30%	115%
Employment in TAZ		2,491	2,671	7%
% total region employees within 10 min. walk from TAZ center		0.41%	0.35%	16%
% total region employees within 6 mi. by SOV from TAZ center		22.62%	9.45%	139%
Environmental Performance Indicators	**Units**			
Land area	Acres	322	644 - 1,288	50% - 75%
Population density	persons/gross acre	12.69	6.64	91%
Dwelling density	DU/gross acre	5.76	2.93	96%
Jobs-to-housing balance	jobs/dwelling unit	2.96	3.07	3%
Employment density	EMS/gross acre	11.87	13.35	11%
Nitrogen oxide (NOx) emissions	lbs/resident/yr.	13.82	23.97	42%
Carbon dioxide (CO_2) emissions	lbs/resident/yr.	2,562.2	4,445.3	42%
Hydrocarbon (HC) pollutant emissions	lbs/resident/yr.	26.82	45.53	42%
Carbon monoxide (CO) emissions	lbs/resident/yr.	207.2	359.1	42%
Home-based vehicle miles traveled	mi/capita/day	7.20	11.50	37%
Non-home-based vehicle miles traveled	mi/capita/day	2.90	6.00	53%
Total vehicle miles traveled	mi/capita/day	10.10	17.52	42%
Personal vehicle energy use	MMBtu/capita/yr.	23.00	40.00	42%

Stormwater Runoff and Pollution Indicators (Total for All 37 Site Pairs)	Percent Change (Conventional/Greenfield less Brownfield) (a)			
	Pasture (Grasslands)		Agricultural Land	
	Low Bound (2x Brownfield Acres)	Upper Bound (4x Brownfield Acres)	Low Bound (2x Brownfield Acres)	Upper Bound (4x Brownfield Acres)
Land area (acres)	50%	75%	50%	75%
Annual runoff	58%	70%	48%	57%
Nitrogen	62%	74%	1%	1%
Phosphorous	66%	79%	-11%	-13%
Suspended solids	67%	80%	30%	35%
Biological oxygen demand	64%	77%	65%	78%
Chemical oxygen demand	61%	73%	65%	78%
Oil and grease	67%	80%	65%	78%
Lead	63%	76%	61%	73%
Copper	61%	73%	47%	56%
Zinc	67%	81%	67%	81%
Cadmium	67%	80%	64%	77%
Chromium	67%	80%	67%	80%
Nickel	67%	80%	67%	80%
Fecal coli	68%	81%	1%	1%
Fecal strep	69%	82%	69%	82%

Notes:

TAZ = traffic analysis zone; HH= household; Ac = acre; Pop = population; SOV = single occupancy vehicle; DU = dwelling unit; MMBTU = millions of British thermal units

Percentage change calculated as: [(Value for conventional – Value for brownfield) / Value for conventional] x 100

- Brownfield sites accommodated the same number of homes and businesses on about one-fourth to one-half the land typically used at corresponding conventional sites.
- Automobile use by residents and employees at brownfield locations are estimated to be substantially lower than at the alternative locations.
  - Average daily vehicle miles traveled per capita would be 42% lower.
  - Personal vehicle energy use per capita would be 42% lower.
- The brownfield redevelopment areas average about 42% lower carbon dioxide emissions per capita relative to conventional development.
- The brownfield redevelopment areas average about 42% lower air pollutant emissions per capita relative to conventional developments.

The positive performance of the environmental indicators at the brownfield locations stems from the fact that the brownfield neighborhoods in this study are denser and more accessible, by most measures. Density is measured primarily by the number of residents, households, or employees per gross acre. Generally, the denser an area, the shorter the distance to various destinations for purposes such as shopping, recreation, and employment. Population density and dwelling density for the average brownfield TAZ in the Baltimore dataset are almost twice that of the average alternative TAZ. Employment density in the average brownfield TAZ is about 11% less than that of the average alternative TAZ.

Accessibility is measured primarily in terms of time required to travel between key origin-destination points within the region. Based on the indicators in Exhibit 5-6, people living and working in the brownfield neighborhoods have better accessibility to other neighborhoods and to points within their TAZs than those in their conventional counterpart areas. Accessibility to transit shows the greatest difference, although walking and automobile travel also show substantial differences. For example, 3.0% of all households in the Baltimore region are within a 30-minute transit ride of the center of the average brownfield TAZ; while the figure for alternative conventional TAZs is 1.3%.

The primary air quality indicators in this study are emissions per capita of nitrogen oxides, carbon dioxide, carbon monoxide, and hydrocarbons. Lower emissions is considered a positive environmental outcome, and more intensive development in more central areas usually results in lower emissions than the same amount of development in less dense areas that are less accessible. However, although total emissions in a region may be at acceptable levels, a particular intensive development can result in local “hot spots” of one or more pollutants. Hot spots are local areas of very high concentrations that may present a health or environmental risk or cause an area to fall out of compliance with air quality attainment goals.

Some pollutants, such as carbon monoxide, are primarily a local health concern. Others, such as carbon dioxide, are greenhouse gases, which contribute to climate change. Some pollutants, such as nitrous oxide (N_20), can have local health impacts and are also greenhouse gases. None of the brownfield development projects in Baltimore is large enough, or has enough industrial or transportation activity to be a regional concern on its own. Analysis of other development in the area was not conducted to determine if, combined with the other development, there might be significantly elevated levels of emissions.

5.3.2 Stormwater Runoff and Pollutant Loads

Total runoff in the region in acre feet would be 58 - 70% lower if development occurs on brownfields rather than in pasture areas, and 48 - 57% lower than agricultural areas (Exhibit 5-6). Compared to pasture areas, loads for all pollutants are substantially lower. Loads of conventional pollutants, such as nitrogen, phosphorous, suspended solids, and biological oxygen demand would be 61% to 82% lower. Metals ranged from 61% to 82% lower. Compared to agricultural areas, the loadings of all pollutants, except phosphorous and nitrogen would be substantially reduced. The loads of phosphorous would increase 11 – 13%, while that of nitrogen would be reduced by only 1%. Agricultural land generally has high concentrations of these substances and, under the brownfield redevelopment scenario, they would continue to generate stormwater runoff. Loads of the other conventional pollutants ranged from 30-82% lower and that of metals ranged from 47 to 81% lower.

As described in Section 5.1, it is estimated that the runoff from redeveloped brownfields would equal that from former uses. While shifts in land use from one type of “developed” use to another may occur, such as from industrial to residential, the amount that runoff would actually change is difficult to estimate as developers may incorporate more effective stormwater management practices. Runoff from the alternative locations would be 71 - 87% lower if left undeveloped than if developed.

Appendix B discusses the details of the methodology, including assumptions and caveats.

6. Dallas-Fort Worth Area

The analysis of the Dallas-Fort Worth area was based on a set of 25 brownfield properties that benefited from U.S. EPA Brownfields Program funding and had redevelopment completed or underway. These sites represent a variety of uses and are scattered throughout Dallas (17 sites), Fort Worth (5 sites), Garland (2 sites), and Grand Prairie (1 site), Texas.

6.1 Brownfield Redevelopment Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in the Dallas-Fort Worth area, and measures of urban form, energy use, air emissions, and estimated stormwater runoff and pollution loads from the brownfield locations. Energy use was measured in terms of personal vehicle energy use per capita. Urban form indicators included density measures (population, dwelling units, and employment), and several indicators of travel efficiency.

Dallas-Fort Worth Brownfield Properties: Using EPA's ACRES database, the EPA Region 6 web site and other online sources, 70 brownfield properties were initially identified in the Dallas area. Several sources were consulted to determine or confirm property locations, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. These sources included data from the U.S. EPA Region 6 Brownfields Team, the City of Dallas Brownfields Program, Fort Worth Environmental Management Department, the assessors' Offices of Dallas and Tarrant counties, and the City of Garland tax database.

This analysis indicated that 25 of the 70 properties had reuse completed or under way and benefited from U.S. EPA Brownfields Program assistance. Properties for which there were firm, specific reuse plans in place were considered as having development underway. For some sites, it was difficult to confirm that U.S. EPA Brownfields Program funds were involved, because documentation of specific funding sources was sparse and local officials did not recollect the situation at a number of sites. The 25 sites are listed in Exhibit 6-1 and their locations are shown in Exhibit 6-2.

Air Quality Impacts and Personal Vehicle Energy Use: Data used to estimate automobile use, energy consumption, and air pollutant emissions, as well as measures of urban form, were provided by the North Central Texas Council of Governments (NCTCOG), which is the Metropolitan Planning Organization (MPO) for a 16-county area which includes the Cities of Dallas and Fort Worth. NCTCOG is a voluntary association of about 230 local governments established to assist in planning for common needs, cooperating for mutual benefit, and coordinating for regional development. This study used data from 12 counties: Collin, Dallas, Denton, Ellis, Hood, Hunt, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise (Exhibit 6-3). For planning purposes, the Council subdivides the region into 6,672 traffic service zones (which is analogous to the term "traffic analysis zone," and for expediency this report will use the term TAZ).

The environmental and urban form indicators were calculated for each of the TAZs in which the brownfields are located. Some of these indicators were scored directly from the regional transportation demand model by the NCTCOG staff, while others were estimated based on the data from the regional transportation demand model. For example, the vehicle energy use and pollutant emissions were estimated based on vehicle miles traveled (VMT) and vehicle trips (VT) data provided by the TMD. The accessibility indicators were also provided by the NCTCOG.

Exhibit 6-1. Dallas-Fort Worth Brownfield Properties Studied

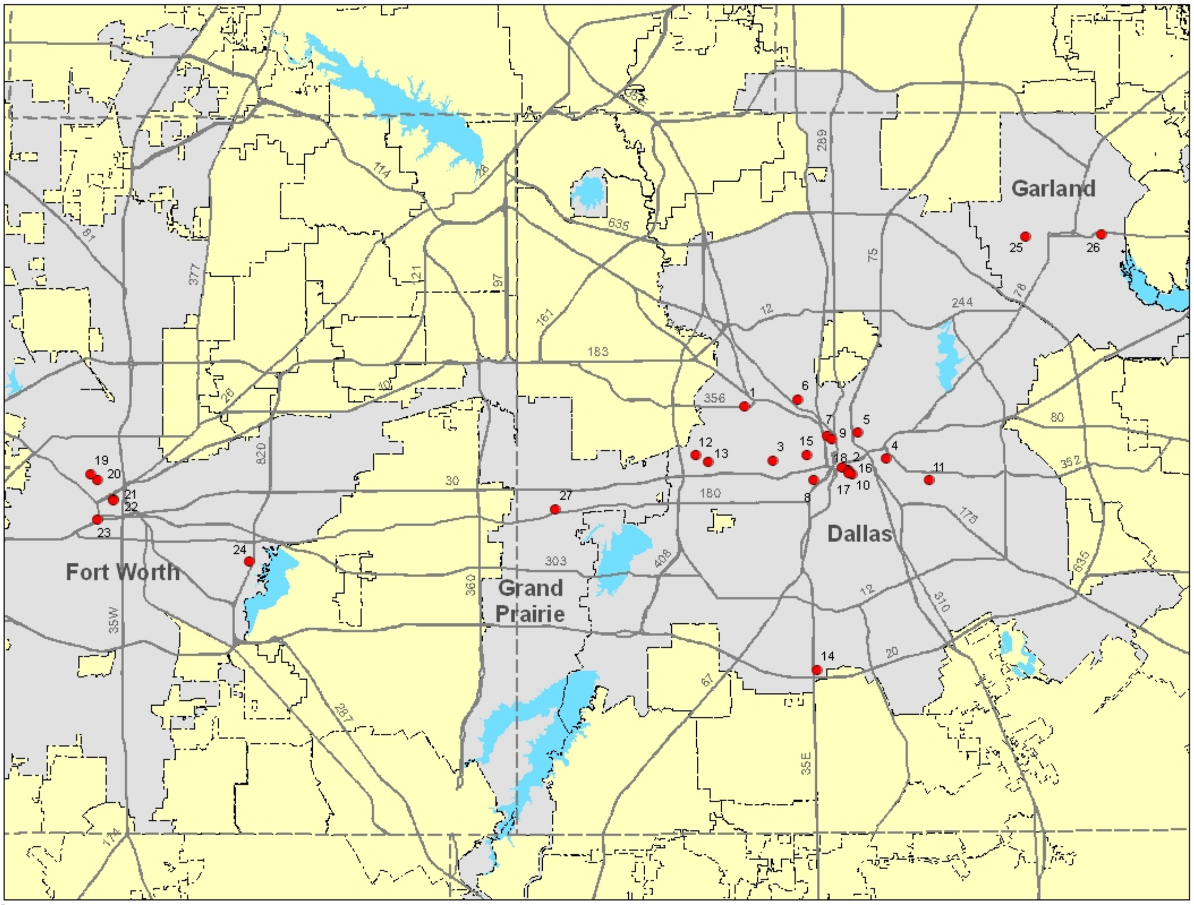
Site No.	Parcel ID	Property Name	Address	ZIP Code	Property Size (acres)	Bldg. Size (SF)	Jobs	Past Use	Current Use	Future Use
Dallas										
1	10872	Union Gospel Mission	3211 Irving Blvd.	75247	0.26	NA	NA	NA	Homeless shelter	Homeless shelter
2	10894	Jack Evans Police Headquarters (old Sears Automotive)	1400 South Lamar St. at Belleview St.	75215	3.20	354,000	880 (combined from different locations)	Auto repair	Police Station	Police Station
3	10911	Los Arboles de Santa Maria	1802-1846 Muncie AVE; & 1802-1838 Bayonne St.	75212	5.05	NA	NA			Affordable housing & mixed use
4	10917	Grand Plaza Shopping Center	3103-3129 Grand Ave.	75215	1.99	NA	NA	10 stores	Retail	Retail
5	10932	Dallas Area Habitat for Humanity, Inc.	3020 Bryan St.	75204	1.05	NA	NA			Residential
6	10959	Cityville, Southwestern Medical District	2222 Motor Street at Bengal St.	75235	5.70	48,000 sf. retail + 278 HUs	125.00	Manufac-turing	Housing	278 HUs & 48K sf. retail
7	13955	Dallas Sports Arena (Victory Park; America Airlines Center)	2500 Victory Ave.	75201	72.00	NA	NA		Indoor sports/enter-tainment complex	
8	13959	Jefferson at Kessler Heights	1520 N Beckley (formerly 1726 Young St.)	75201	27.00	674 HUs	NA	Mixed	Apartment; 674 units	Apartment; 674 units
9	13947	Jefferson North End	2323 North Field St. (River St. & Field St.)	75202	11.00	540 HUs	12.00	Commer-cial & light industrial	Residential	Residential
10	13953	South Side on Lamar	1409 South Lamar	75215	17.50	1.4 MM sf.	200.00	Comm. & light industrial	Mixed: commercial, res., retail, hospitality	Mixed: commercial, res., retail, hospitality
11	13943	Larry Johnson Recreation Center	3700 Dixon Ave. and Wullchleger St.	75210	2.60	14,260	5.00	Apartments	Recreation center	Recreation center
12	13950	DART passenger transfer location (PTL)	5057 Singleton Blvd.	75220	1.80	NA	3.00	Auto repair & salvage	PTL	PTL
13	13939	Pal Ex (American Pallet Recyclers)	2401 Vinson St.	75212	26.40	NA	91.00	Manufac-turing	Light industry	Light industry
14	15914	BAC5 Business and Job Training Complex	208 East Wheatland Rd.	75241-5311	0.80	NA	139 F/T & P/T	Vacant pasture & woodland	Vacant pasture & woodland	Job training center

Exhibit 6-1. Dallas-Fort Worth Brownfield Properties Studied (Continued)

Site No.	Parcel ID	Property Name	Address	ZIP Code	Property Size (acres)	Bldg. Size (SF)	Jobs	Past Use	Current Use	Future Use
15	49501	Belleview-Lamar Condos (Beat Condos)	918 Powhattan St. (formerly 1300 South Lamar St.)	75215	4.30	NA	NA	Oil storage, mfg., warehouse	75 Condos	390 Condos
16	79401	.26 Acre Commercial Property	969 & 971 S. Lamar	75215	0.26	1 flr. retail; 1 flr. storage	NA	NA	Liquor store; & warehouse	Retail & storage
17	79521	Dallas County Community College District Offices	1601 & 1700 S. Lamar (So. Side of Lamar)	75215	2.40	NA	Sales, mfg, warehouse	NA	Office	Office
Fort Worth										
18	12222	Ellis Pecan	1012 N Main St.	76164	0.30	NA	NA	Vacant warehouse	Vacant	Office
19	12223	LaGrave Field/American Cyanamid	600 No. Jones/ 500 No. Commerce	76164	34.00	NA	NA	Petrol. Refining catalyst operation	Vacant	Mixed use
20	12224	Fourth and Elm downtown	Fourth and Elm St. downtown	76102	1.00	NA	NA	Mfg/vacant	Vacant	Urban park
21	12225	Cotton Depot Freight Terminal Downtown	555 Elm St.	76102	5.80	210 loft apartments	NA	Freight terminal & warehouse	Loft-style apartments	Loft-style apartments
22	15747	Tarrant Community College	5901 Fitzhugh Ave.	76119	3.64	NA	NA	NA	Vacant bldg	Office & corp. services training center
Garland										
23	10871	Continental Emsco	2441 Forest Ln.	75042	14.80	NA	NA	NA	Warehouse/ industrial	Warehouse/ industrial
24	15152	Former DDI Facility	1500 East Highway 66	75040	20.90	NA	NA	NA	NA	Municipal fire admin & training facility
Grand Prairie										
25	11956	"300 NW 4th St, Dallas, TX"	300 4th St. NW	75050	1.87	NA	NA	NA	Office	Office

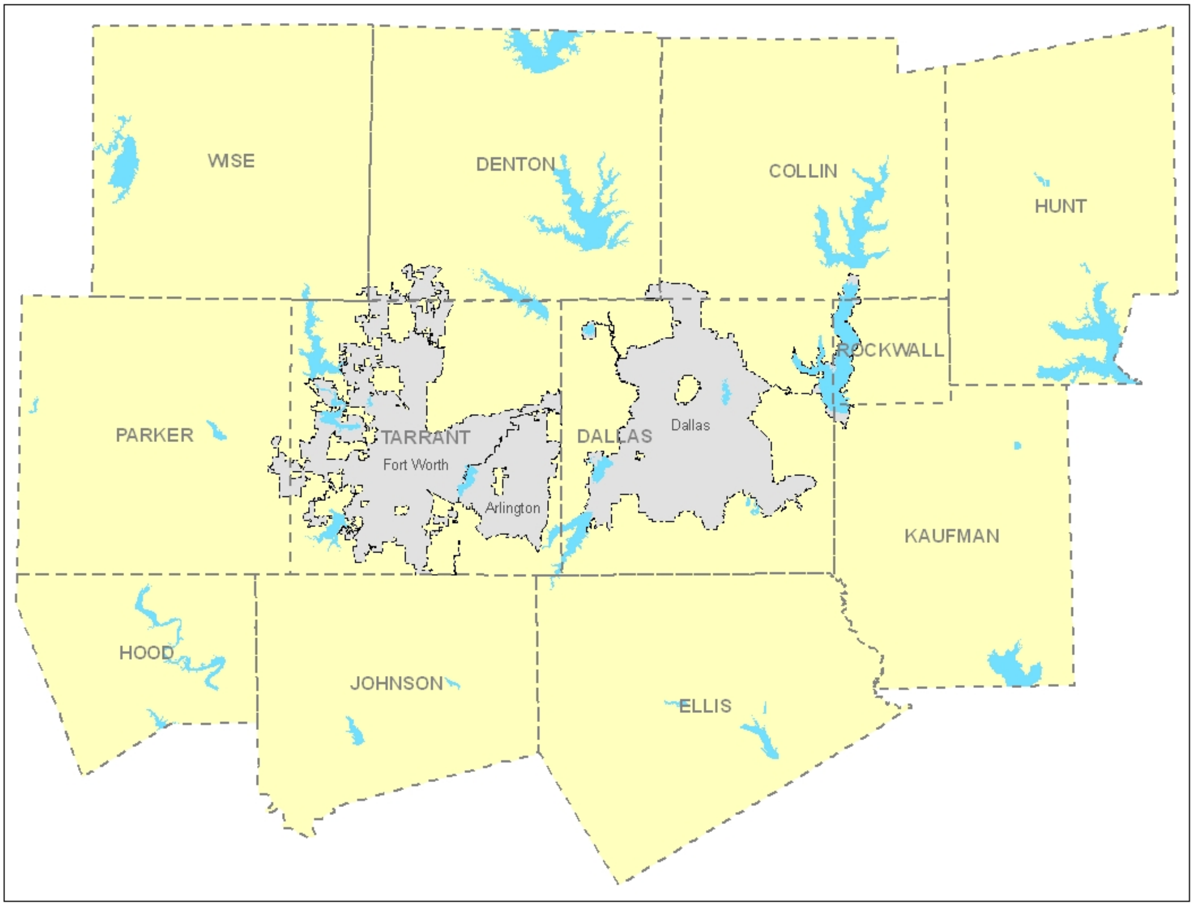
Notes: HU = housing units.

Exhibit 6-2. Locations of 25 Brownfield Sites In Dallas-Fort Worth



ields

Exhibit 6-3. North Central Texas Council of Governments Planning Area



Water Quality Impacts: The Long-Term Hydrologic Impact Assessment (L-THIA) watershed management model was used to estimate stormwater runoff and pollutant loads from each site. The model calculates runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. L-THIA contains data on average county precipitation, generally accepted soil curves for each type of land use and soil (USDA 1986). Data on site location, parcel size, and land use type are shown in Exhibit 6-1. Hydrologic soil group data were extracted from USDA's soil survey data (USDA 2008 and 2009), as L-THIA's look-up maps were out of service at the time of this analysis.

Estimated runoff from former uses of the Dallas brownfield sites was compared to those of the redeveloped brownfield sites. Based on this analysis, stormwater runoff from the 25 redeveloped brownfields is estimated to be about 2.7% less than that from the former uses. For six properties totaling 124 acres, land use type did not change, and for five properties totaling 29 acres, former uses were unknown. For this calculation, the land uses for the latter properties were set equal to the new uses. This result is caused by shifts in land use from one type of developed use to another, such as from industrial to residential or one type of commercial use to another.

Appendix B provides further detail on the application of L-THIA, key assumptions, and limitations of the approach.

6.2 Alternative Conventional Development Scenario

The alternative conventional scenario identified locations where the same type of development would likely have been built if they had not been built on the brownfields, and estimated the environmental performance of these locations.

Alternative Conventional Locations: For each brownfield site, an alternative location was assigned, based on recent development patterns in the region. Since brownfield sites are only a small portion of total development in the region, it is reasonable that the alternative development would generally follow the prevailing patterns. The development counterpart for each brownfield site was assigned to one of the top 10% fastest growing locations (667 TAZs). The fastest growing TAZs were based on population and employment shifts from 2000 to 2005, where the percentage of the regional population and employment for each TAZ experienced the greatest increase in population and employment with respect to all other TAZs.[12] The high-growth areas are shown in Exhibit 6-4. Alternative locations for each of the 25 brownfield sites are shown in Exhibit 6-5. These locations were selected from the high-growth employment areas and high-growth residential areas using a statistical site selection procedure. The use of a statistical site selection procedure ensured that the process was impartial.

Alternative Conventional Development Size: Because development generally consumes more acreage in suburban and rural areas than in more dense, urban areas, it is anticipated that most of the 25 alternative locations would require more land than their brownfield counterparts. Based on a range of values derived from literature on land use patterns, it was assumed that the conventional/greenfield sites would generally require an average of two to four times the acreage of their brownfield counterparts. Land use decisions are inherently influenced by a number of site-specific factors. As a result, there is a wide variation in the amount of land consumed by similar uses in different areas,

[12] To reflect growth in both employment and residents, the 25 brownfield sites were divided into two groups according to whether, based on their redevelopment use, they are more likely to be located in, or economically linked to, a residential area (11 sites) or a non-residential area (14 sites).

Exhibit 6-4. High Growth TAZs in the 12-County Dallas-Fort Worth Planning Area

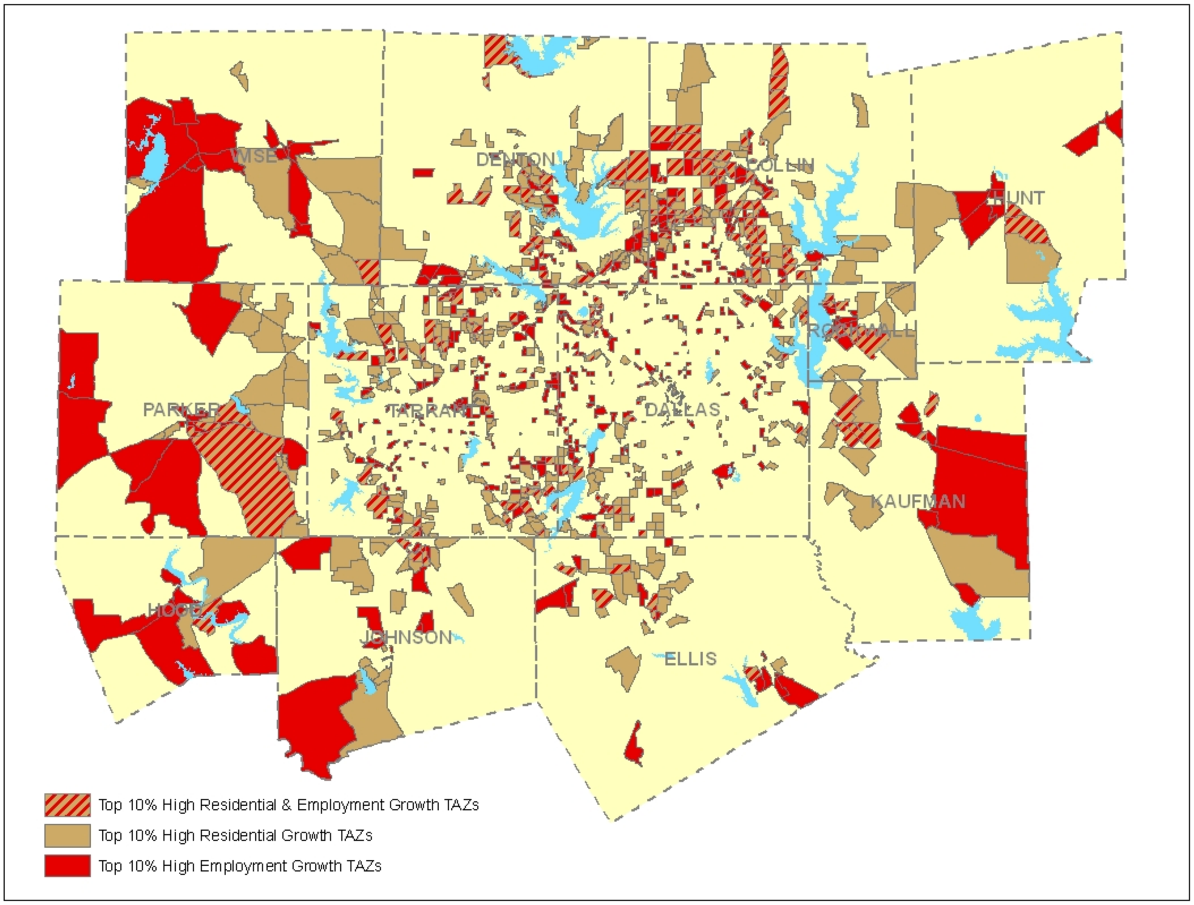
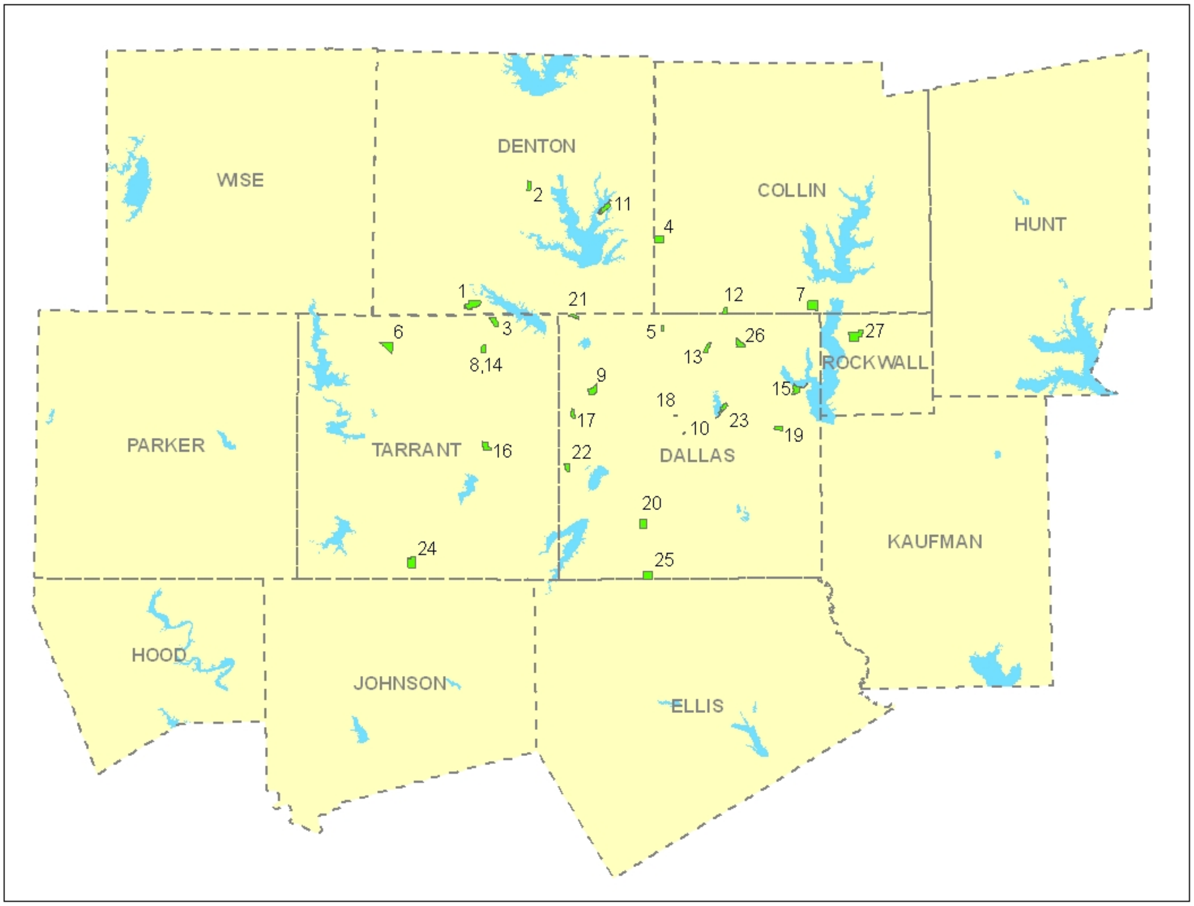


Exhibit 6-5. Alternative Conventional Locations in the Dallas–Fort Worth Planning Area: 25 Sites



or even at properties within close proximity. Reviewing zoning ordinances will not necessarily result in an accurate estimate of likely land consumption**.** Thus, an average acreage multiplier of two is used for a more conservative estimate and an average of four is used for an upper bound.

Air Quality and Personal Vehicle Energy Consumption: Using information on the conventional development locations, acreage, and categories of use, the environmental characteristics of these locations were described according to indicators scored from the data in the TMD, with a procedure identical to that described above for the brownfield sites.

Water Quality: Using information on the alternative development locations, which were assumed to be greenfields for the stormwater modeling, acreage, and categories of use (e.g., commercial, residential, agricultural), the stormwater runoff and pollutant loads from these locations were estimated with the L-THIA model in a procedure identical to that described above for the brownfield sites.

It was assumed that the new construction would take place either in a former vacant pasture area or on former agricultural land.[13] To obtain the net new runoff contribution of the greenfield development, the existing runoff (pasture or agricultural area footprint) was subtracted from the runoff expected from the developed uses, which were primarily commercial and industrial. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites were also factored in. These calculations are described in greater detail in Appendix B. Using two land use categories provides a range of acceptable values rather than a single estimate. This type of estimate is appropriate, since the precise location of the greenfield site within the TAZ or census tract is unknown.

6.3 Comparison of Brownfield and Conventional Scenarios

For each site pair, the estimated indicators were compared, and totals for all sites were averaged. The results of the air quality and energy analysis were generally expressed in terms of percent difference in VMT and emissions associated with the brownfield site compared to its conventional alternative on a per capita basis. The results of the stormwater runoff analysis were expressed in terms of percent difference in stormwater runoff and pollutants from brownfields in the group of 25 site pairs. A number of limitations and caveats apply to this comparison. These are discussed in Appendix B, Methodology.

6.3.1 Air Emissions and Personal Vehicle Energy Use

The average brownfield scores were positive for all indicators. The calculations show that nearly all (21 out of 25) redeveloped brownfield sites result in better environmental performance than similar conventional development. The key performance measures are shown in Exhibit 6-6. These results indicate the following:

[13] The predominant land uses in the region are agricultural, range, and open land. It is sometimes difficult to distinguish among these uses from satellite images available on Google Earth. L-THIA' Basic module offers three land use categories for undeveloped land: forest, pasture/grassland, and agricultural.

Exhibit 6-6. Comparison of Environmental Indicators in the Dallas-Fort Worth Area: Average Differences Between 25 Site Pairs

	Brownfield Average	Conventional Average	Percent Change (Conventional less Brownfield) (a)
Accessibility Indicators			
Households (HH) in TAZ	208	489%	57%
% total region households within 10 min. walk from TAZ center	0.02%	0.02%	2%
% total region households w/in 30 min. transit ride from TAZ	NA	NA	NA
% total region households w/in 6 mi. by SOV from TAZ center	5.52%	4.07%	36%
Employment in TAZ	753	797	5%
% total region Employees within 10 min. walk from TAZ center	0.20%	0.05%	307%
% total region Employees within 30 min. transit ride from TAZ	NA	NA	NA
% total region Employees within 6 mi. by SOV from TAZ center	8.87%	4.13%	115%

Environmental Performance Indicators	**Units**	Brownfield Average	Conventional Average	Percent Change (Conventional less Brownfield) (a)
Land Area	Acres	265	530 – 1060	50% to 75%
Population Density	persons/gross acre	5.90	5.14	15%
Dwelling Density	DU/gross acre	2.86	2.65	8%
Transit Adjacency to Housing	% pop. w/in 1/4-mi.	90.16	31.68	185%
Jobs-to-Housing Balance	jobs/dwelling unit	3.62	1.63	122%
Employment Density	emps/gross acre	10.72	3.75	186%
Transit Adjacency to Employment	% empl. w/in 1/4-mi.	91.40	34.42	166%
Open Space Connectivity	0-1 scale	NA	NA	NA
Nitrogen Oxides (NOx) emissions	lbs/capita/yr.	16.50	35.40	53%
Carbon dioxide (CO_2) emissions	lbs/capita/yr.	3,060	6,566.12	53%
Hydrocarbon (HC) Emissions	lbs/capita/yr.	32.03	68.72	53%
Carbon Monoxide (CO) Emissions	lbs/capita/yr.	247.48	531.03	53%
Total Vehicle Miles Traveled	mi/capita/day	12.06	25.88	53%
Total Vehicle Trips	trip/capita/day	1.48	1.95	24%
Personal Vehicle Energy Use	MMBtu/capita/yr.	27.51	59.04	53%

Stormwater Runoff and Pollution Indicators (Total for All 25 Site Pairs)	**Percent Change (Conventional/Greenfield less Brownfield) (a)**			
	Pasture (Grassland)		**Agricultural Land**	
	Low Bound (2x Brownfield Acres)	**Upper Bound (4x Brownfield Acres)**	**Low Bound (2x Brownfield Acres)**	**Upper Bound (4x Brownfield Acres)**
Land area (Acres)	50%	75%	50%	75%
Annual Runoff	43%	52%	32%	38%
Nitrogen	54%	66%	-41%	-48%
Phosphorous	62%	78%	-49%	-55%
Suspended Solids	66%	79%	-1%	-3%
Biological Oxygen Demand	60%	78%	59%	72%
Chemical Oxygen Demand	60%	79%	66%	79%
Oil and Grease	60%	80%	67%	80%
Lead	55%	70%	64%	76%
Copper	44%	61%	64%	76%
Zinc	69%	79%	65%	77%
Cadmium	54%	63%	41%	46%
Chromium	39%	55%	26%	28%
Nickel	62%	79%	66%	79%
Fecal coli	63%	78%	-29%	-29%
Fecal strep	54%	75%	60%	77%

Notes: NA: Data not available; DU = dwelling units; MMBTU = Millions of British thermal units; TAZ = traffic analysis zone; HH = household; Ac = acre; Pop = population; SOV = single occupancy vehicle; DU = dwelling unit

(a) Percentage change calculated as [(Value for conventional – Value for conventional / Value for conventional] x 100

- Brownfield sites accommodated the same number of homes and businesses on about one-fourth to one-half the land typically used at corresponding conventional sites.

- Automobile use by residents and employees at brownfield locations is estimated to be substantially lower than at the alternative locations.

    - Average daily vehicle miles traveled per capita would be 53% lower.
    - Average daily vehicle trips per capita would be 24% lower.
    - Personal vehicle energy use per capita would be 53% lower.

- The brownfield redevelopment areas average about 53% lower carbon dioxide emissions per capita relative to conventional development.

- The Brownfield redevelopment areas average about 53% lower air pollutant emissions per capita relative to conventional development.

The positive environmental indicator values at the brownfield locations relate to the fact that the brownfield neighborhoods in this study are denser and more accessible by most measures. Density is measured primarily by the number of population, households and employees per gross acre. Generally, the denser an area, the shorter the distance to various destinations for purposes such as shopping, recreation, and employment. Dwelling units per gross acre for the average brownfield TAZ in this study is about is 8% greater than for the average conventional location and employees per gross acre at the average brownfield locations is 2.8 times that of the average conventional TAZ.

Accessibility is measured primarily in terms of time required to travel between key origin-destination points within the region and distance to transit. Based on the indicators in Exhibit 6-6, people working in the brownfield neighborhoods have better accessibility to other neighborhoods and to points within their TAZs than those in their conventional counterparts. For example, 9% of all employees in the region are within six miles by single-occupancy vehicle from a TAZ center for the average TAZ where a brownfield is located. The average figure for the conventional TAZs is 4%. Ninety percent of all employees and households in the brownfield areas are within ¼ mile of a transit facility in the brownfield TAZs, compared to only 32% for the conventional TAZs. Some of the accessibility measures for households, however, indicate no clear trend.

The primary air pollution indicators in this study are per capita emissions of pollutants such as nitrogen oxides, carbon dioxide, and carbon monoxide. Lower emissions are considered a positive environmental outcome, and more intensive development in more central areas usually results in lower emissions than the same amount of development in less-dense areas that are less accessible. However, although total emissions in a region may be at acceptable levels, a particular intensive development can result in local "hot spots" of one or more pollutants.

Hot spots are local areas of very high concentrations that may present a health or environmental risk or cause an area to fall out of compliance with air quality attainment goals. None of the brownfield development projects in Dallas is large enough, or has enough industrial or transportation activity, to be a regional concern on its own. However, this study did not analyze other development in the area to determine if, combined with the other development, there might be significantly elevated levels of emissions.

6.3.2 Stormwater Runoff and Pollutant Loads

Runoff in acre feet would be 43 - 52% lower if development occurs on the brownfield rather than pasture areas, and 32 - 38% lower than if the alternative sites were in woodland areas (Exhibit 6-6). Conventional pollutants loads, such as nitrogen, phosphorous, suspended solids, biological oxygen demand, and chemical oxygen demand, were 54 - 80% lower than development on grasslands and 55 - 80% lower than development on woodlands.

Based on the calculations using L-THIA, stormwater runoff from the 25 developed brownfields is estimated to be about 2.7% less than that from former uses within Dallas-Fort Worth. This result is caused by shifts in land use from one type of developed use to another, such as from industrial to residential. For six properties totaling 124 acres, land use type did not change, and for five properties totaling 29 acres, former uses were unknown. The land uses for the latter properties were set equal to the new uses. Runoff at the alternative greenfield locations would be 47 - 65% lower if left undeveloped than if developed. It is unclear how much runoff would actually change, because developers may incorporate more effective stormwater management practices. These issues are further discussed in Appendix B.

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References are divided into two sections: one addressing air quality, energy, and land use, and one addressing stormwater runoff and water quality.

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Appendix A. Vehicle Miles Traveled: Empirical Results of Previous Studies

This appendix reports the empirical results of a number of studies that compared the environmental performance of developing on brownfield and infill properties to similar development on greenfield properties. Almost all of these studies indicate that there are significant environmental benefits from developing on brownfield and infill areas compared to greenfield areas. Comparing the results of these studies is complicated by the fact that city characteristics, methodologies used, and study objectives all varied from one study to another. This appendix summarizes an analysis of vehicle miles traveled (VMT) estimates from 12 existing studies of brownfield and infill development compared to greenfield development. VMT was the only variable that could be consistently tracked across all the studies.

Methodology

The average difference in environmental performance (i.e., changes in vehicle miles traveled (VMT), vehicle trips, emissions, and land consumption) estimated by all 12 studies was reviewed and the variation of the results among the studies was examined. Usually, the smaller the variation, the greater confidence that the average (arithmetic mean) is likely to be a good indicator of environmental performance at other brownfield sites. In order to develop these calculations, it was necessary to make adjustments to the reported data.

Because the studies expressed results in different metrics, an average benefit could not be directly calculated. Some of the studies expressed results in terms of nominal values, such as tons of emissions or VMT for the entire city. Other studies expressed estimates on a per capita basis, for a particular neighborhood, for a group of neighborhoods or for analysis zones. To enable comparison of results among the studies, the estimates of VMT were adjusted to normalize all results on the basis of total development shifted from the brownfield or infill locations to the greenfield locations. Thus, the analysis essentially compares VMT on a per capita or per job basis.

Findings

Normalizing all the conclusions of these studies and expressing the VMT changes in terms of percentage change from the baseline (brownfield/infill development scenario), provided consistent data for VMT for 12 cities (Exhibit A-1). Vehicle miles traveled is one of the most important indicators of environmental performance. It is usually directly related to emissions and vehicle energy use, although it is not the only variable that affects emissions. (Some emission constituents are more directly related to vehicle starts than miles driven.)

Exhibit A-1. Cities Included in the Previous Studies

1. Atlanta, GA (Shroeer 1999)
2. Baltimore, MD (EPA 2001a)
3. Boston, MA (EPA 2002)
4. Charlotte, NC (EPA 2002)
5. Denver, CO (EPA 2002)
6. Dallas, TX (EPA 2001a)
7. Nashville, TN (NRDC 2003)
8. Sacramento, CA (NRDC 2003)
9. San Diego, CA (EPA 1999)
10. Montgomery County, MD (EPA 1999)
11. West Palm Beach, FL (EPA 1999)
12. BCD (Berkeley, Charleston, Dorchester), SC (IEC 2003)

Exhibit A-2 provides summary statistics for the 12 study areas. If the brownfield/infill development in these areas were shifted to greenfield areas, the VMT by people who live or work in these areas and were included in the reallocation would increase by an average of 65%. The range is 23% to 156%, and the standard deviation is 45%.

Exhibit A-2. Estimated Changes in VMT Per Capita: Previous studies

	Change (Reduction) in VMT (Brownfield as a % of Greenfield)	Change in VMT* (Greenfield – Brownfield as % of Brownfield)
Range	39% - 81%	23% - 156%
Average	61%	65%
Standard deviation	NA	45%
Average of lowest 7 studies	75%	34%
Reasonable consensus	61% - 75%	34% - 65%

* Increase in VMT due to shifting development from brownfield or infill to greenfield. If the development occurred on the greenfield, VMT would be 34 - 65% higher than on the brownfield, on average.

Considering the limited number of cities and the great variety of urban characteristics, a 45% standard deviation is not surprising. Although the estimated average increment (65%) may be representative of the population of brownfield or infill projects, the large standard deviation indicates that there is a significant range of possibilities. However, it is clear that even the lowest values indicate significant benefits. If the five highest values were eliminated, the average for the remaining seven cities (+34%) still indicates substantial improvement in VMT as a result of brownfield redevelopment compared to greenfield development. Thus, a conservative interpretation of this data would be that:

- If the brownfield or infill sites were not developed, VMT would be 34 - 65% higher, using the "consensus" estimate (which omits the high values). As stated above, this conclusion is a conservative interpretation, since the five highest values were excluded from the calculation of the average. The comparable figure estimated for the average of the five regions in this study is 46 - 133%, slightly outside this range .
- Another way of expressing this is that the average brownfield VMT as a percent of their counterpart greenfield VMT for the 12 studies is 61 - 75%, using the consensus estimate. The average value for the five regions addressed in this study is 43 - 67% (shown in Exhibit 1-2). That is, the brownfield locations would produce 43 - 67% less VMT per capita than the greenfield locations.
- These estimates also do not fully account for some benefits, such as those arising from intrazonal changes in modal shares of trips. That is, they represent a somewhat conservative estimate.

Appendix B. Methodology

Introduction

This study tests an analytical approach to quantifying environmental impacts of multiple redevelopment projects in a municipal area. For each of five cities, all known brownfield sites that benefited from U.S. EPA Brownfields Program assistance and had redevelopment completed or under way were identified. Most of these properties are in close-in, densely developed areas. The study also identified locations that were reasonable alternatives for each of the brownfield sites, based on prevailing development trends in the region. It was assumed that had the development not occurred on the brownfield, it would have gone to these locations. The environmental performance of both sets of locations were measured and compared, in terms such as vehicle miles traveled per capita, air pollutant emissions per capita, personal vehicle energy use per capita, and stormwater runoff and pollutant loads. The environmental performance measures were developed with data from regional transportation demand models, a watershed management model, and INDEX, a geographical information system-based analytical tool (EPA 2001b, Allen 2008).

The regions studied were selected based on several factors, including a significant number of brownfield properties that had benefited from U.S. EPA Brownfields Program funding and had development completed or under way, the availability of information about the reuse status of the brownfield sites, and the availability of data that could be used as indicators of local environmental performance.

Exhibit B-1 provides summary information for the municipal areas studied. The study team identified 163 brownfield properties that met the above criteria. This figure is 35-40% of the total number identified in EPA's ACRES property profile form database in the five cities. The other sites were not included in the study either because they had not been redeveloped or because confirmation that the property had benefited from U.S. EPA Brownfields Program assistance could not be obtained. A few sites were excluded because it was difficult to categorize their use type for purposes of this study, such as a property that was used for a bridge approach. These sites account for a small portion of total (brownfield and non-brownfield) development acreage in these areas. However, their development has been important to the communities in overcoming issues with properties that have been obstacles to redevelopment.

Exhibit B-1. Municipal Areas Included in Study

City	No. of Brownfield Properties [(a)]	Brownfield Acreage	City Population in Thousands (Year)	City area (Sq. Mi.)	Planning Area	Population in Planning Area (millions)
Seattle	25	87	592.8 (2007)	83.87	4-county area	3.6
Minneapolis-St. Paul	37	80	676.7 (2007)	114.60	7-county area	2.9
Emeryville	39	183	10.1 (2009)	1.9	9-county area	5.1
Baltimore	37	322	636.9 (2008)	92.07	5 counties & Baltimore City	2.5
Dallas-Ft. Worth	25	266	2,026.6 (2009)	678	12-county area	6.5
Total	163	938				

(a) Properties that have received U.S. EPA Brownfields Program assistance and have been, or are being, redeveloped.

Methodology Overview

For each of the five municipal areas, the environmental performance of the two development scenarios were compared. (1) In the *brownfield redevelopment scenario,* the environmental performance was estimated for all identified brownfield sites in the selected municipalities that had benefited from EPA Brownfields Program funding where redevelopment was completed or under way. (2) In the *alternative conventional development scenario*, reasonable alternative locations for each of the brownfield sites were identified, a quantity of residential and commercial space matching each brownfield redevelopment project was allocated among these areas, and environmental performance of these locations was estimated. Environmental performance was measured in terms such as carbon dioxide and air pollutant emissions per capita, personal vehicle energy use per capita, and stormwater runoff and pollutant loads. The differences between the environmental performance parameters represent relative environmental benefits of redeveloping brownfield sites compared to similar development on conventional sites.

The following sections describe the basic steps taken to assemble the brownfield and conventional scenarios, and the process used to compare the environmental outcomes of the two.

Brownfields Development Scenario

The brownfields scenario was described in terms of the number and characteristics of brownfield sites in each city, and measures of urban form and environmental performance. Urban form indicators include metrics such as population density, travel efficiency, and jobs-to-housing balance. To specify the brownfields development scenario, the following activities were undertaken:

Identification of Brownfield Sites

Using a number of sources, such as U.S. EPA's ACRES database, EPA regional web sites and staff, and other online sources, brownfield properties were identified in each of the five municipal areas. For each property, information from several sources, including municipal and county data bases, non-profit organizations, tax assessor records, building permit files, and local government officials was used to determine or confirm property location, acreage, use type (commercial, industrial, recreational, and residential), and the status of use. Based on this information, about two-thirds of the sites were eliminated from the study, either because they were not developed or it could not be confirmed that U.S. EPA Brownfields Program assistance was used at the site.

This analysis resulted in a list of 163 properties that had reuse completed, under way, or planned and had benefited from U.S. EPA Brownfields Program assistance. Properties for which there were firm, specific reuse plans in place were considered as having development under way. These properties are listed along with basic descriptive information in Sections 2 through 6 of this report (25 in Seattle, 37 in Minneapolis-Saint Paul, 39 in Emeryville, 37 in Baltimore, and 25 in Dallas-Fort Worth).

Estimation of Impacts on Air Quality and Personal Vehicle Energy Use

Data used to estimate automobile use, energy consumption, and air pollutant emissions associated with the brownfield locations were provided by metropolitan planning organizations (MPOs) in each region. These organizations are typically responsible for transportation planning and, often, land-use planning in their regions, which generally cover several counties. The five MPOs in this study had planning areas that ranged from four to 12 counties. They each maintain a transportation demand model, which contains the basic data used for this study. For modeling purposes, each MPO divides the region into grids of cells of varying size known by terms such as traffic analysis zones (TAZs), travel analysis zones, and traffic service zones.[14] Using this data and INDEX planning support software (EPA 2001b, Allen 2008), environmental measures were developed at the TAZ level. Urban form indicators included items such as density measures (population, dwelling units, and employment per gross acre), jobs-to-housing balance, and several transportation accessibility indicators. The indicators are listed in Exhibit B-2.

Estimation of Impacts on Water Quality: Overview

For the purposes of stomwater modeling, all alternative conventional sites were assumed to be greenfields. For each brownfield site and corresponding alternative location, pre-development and post-development stormwater runoff and pollutant loads were estimated. These values were summed for each region and the differences between brownfield development scenarios and conventional/greenfield development scenarios were tabulated and evaluated.

The study used the Long-Term Hydrologic Impact Assessment (L-THIA) watershed management model to estimate stormwater runoff and pollutant loads from each site. To select the model for use in this study, a review of the models evaluated in two EPA reports (U.S. EPA 2005, and 2007) and other sources was conducted. This review concluded that L-THIA offered the best policy-level options of the models evaluated. In the event that more detailed analysis would be needed, the EPA Storm Water Management Model (SWMM) was suggested as an alternative. SWMM is a design model and, to be used properly, it requires site-specific data, which would require a more resource-intensive effort. Given the fact that the specific design parameters for the properties addressed in this study are sparse, it was determined that L-THIA would better meet the needs of the project objectives.

As a policy level model, L-THIA makes several simplifying assumptions that a design model generally would not. These include:

- Neglecting the contributions of snowfall to runoff;
- Neglecting the effect of frozen ground that can cause increases stormwater runoff during cold months; and
- Neglecting variations in antecedent moisture conditions that affect infiltration rates.

Since these simplifications are applied equally to brownfield and greenfield development scenarios, the effects on the relative differences in runoff are likely to be negligible.

L-THIA uses the generally accepted soil curve method for calculating runoff. It has default features as well as the ability to input site-specific values, and contains soil type look-up maps as well as county-specific precipitation data. These features could provide considerable time savings over some models that require locating and importing soil type and precipitation data from third party sources.

[14] A traffic analysis zone (TAZ) is a special area delineated by state and/or local transportation officials for tabulating traffic-related and other planning data. A TAZ usually consists of one or more census blocks, block groups, or census tracts.

Exhibit B-2. Indicators of Environmental Performance

Accessibility Indicators
Households (HH) in TAZ
% total region households w/in 10 minute walk from TAZ center
% total region households w/in 30 minute transit ride from TAZ center
% total region households w/in 6 miles by single occupant vehicles (SOV) from TAZ center
Employment in TAZ
% total region employees within a 10 minute walk from TAZ center
% total region employees within a 30 minute transit ride from TAZ center
% total region employees within 6 miles by single occupant vehicles (SOV) from TAZ center

Environmental Performance Indicators	**Units**
Land area	Acres
Population density	persons/gross acre
Transit adjacency to housing	% population within 1/4-mi.
Jobs-to-housing balance	jobs/dwelling units (DU)
Employment density	Employees/gross acre
Transit adjacency to employment	% employees within 1/4-mi.
Nitrogen oxides pollutant (NOx) emissions	lbs/resident/yr.
Carbon dioxide (CO_2) emissions	lbs/resident/yr.
Hydrocarbon pollutant (HC) emissions	lbs/resident/yr.
Carbon monoxide pollutant (CO) emissions	lbs/resident/yr.
Home-based vehicle miles traveled (VMT)	mi./capita/day
Non-home-based vehicle miles traveled (VMT)	mi./capita/day
Total vehicle miles traveled (VMT)	mi./capita/day
Home-based vehicle Trips (VT)	Trips/capita/day
Non-Home-Based Vehicle trips (VT)	Trips/capita/day
Total vehicle Trips (VT)	Trips/capita/day
Dwelling density	Dwelling units (DU)/gross acre
Personal vehicle energy use	Millions of British Thermal Units (MMBtu)/capita/yr.

Stormwater Runoff and Pollution Indicators	**Units**
Land area (acres)	Acres
Annual runoff	Acre feet
Nitrogen	Lbs.
Phosphorous	Lbs
Suspended solids	Lbs
Biological oxygen demand	Lbs
Chemical oxygen demand	Lbs
Oil and grease	Lbs
Lead	Lbs
Copper	Lbs
Zinc	Lbs
Cadmium	Lbs
Chromium	Lbs
Nickel	Lbs
Fecal coliform	Millions of coliform
Fecal streptococcus	Millions of coliform

Notes:

TAZ = traffic analysis zone, travel analysis zone, transportation analysis zone, or similar terms; HH= household; Ac = acre; Pop = population; SOV = single occupancy vehicle; DU = dwelling unit; MMBTU = millions of British thermal units

(a) Percentage change calculated as [(conventional value less brownfield value) / conventional value] x 100

Soil types are derived from USDA and L-THIA data. For a number of locations, the L-THIA look-up maps were out of service or did not function, and the data were derived from the USDA Web Soil Survey (USDA 2008 and 2009). Soil type A represents soils with high infiltration rates and type D represents the lowest infiltration rates. For the greenfield locations, soil types for the closest matching census tracts were used. The sizes of the greenfield sites were estimated from several sources as described in subsequent sections of this appendix, and a range of values was used in the L-THIA analysis. The range reflects a conservative estimate that results in the greenfields development averaging twice the acreage of the brownfield sites, and an average upper-bound estimate of four times.

L-THIA Application at Brownfield Sites

L-THIA estimates stormwater runoff as a function of precipitation, site size, type of land use (e.g., commercial, industrial, residential), and hydrologic soil group. It estimates pollutant loads as a function of runoff, soil type, and land use type. L-THIA contains data on average county precipitation, generally accepted soil curves (USDA 1986), and hydrologic soil groups.

Data on brownfields locations, site size, and land use type for each brownfield site were entered into the model. L-THIA provided the long-term average precipitation values. Soil groups were derived from either L-THIA's internal database or USDA's soil survey data.[15] The sources of these data for each of the five regions are described in the report section for that region. Developed land use types were broad categories: commercial, industrial, and high- and low-density residential. L-THIA offers an option to use more disaggregated land use categories for some land uses. However, since the objective of this study is to develop broad comparisons and an approach that can be practicably emulated, the study team used the "Basic" run option, which includes three undeveloped land uses and four developed land uses.

For each brownfield site, estimated runoff and pollutant loads were calculated for both the former brownfield land use and for the redeveloped brownfield land use. Even though a property's size and location does not change, its runoff can change if land use type changes, such as if a former industrial property is redeveloped as retail space. The total of these two calculations were tabulated for all the brownfields in each city and compared. The differences between these two figures were relatively small, ranging from -3.5% to 6.2% (Exhibit B-3).

Exhibit B-3. Change in Runoff on the Brownfield Sites

City	% Change in Runoff (a)
Seattle	- 3.5%
Minneapolis	- 0.6%
Emeryville	6.2%
Dallas	- 2.7%
Baltimore **(b)**	Unknown **(b)**

(a) (Undeveloped runoff – Developed runoff) / Undeveloped runoff
(b) Assumed to be zero. Data on pre-developed land uses in Baltimore are considered unreliable.

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[15] During the period of this study, the soil type look-up maps were disabled for several regions. These data were extracted from USDA's soil survey data (USDA 2008, 2009). For some locations, soil groups were not available. For most of these sites, assumptions were made, based on the prevailing soil groups in nearby areas. Where there was no basis for an assumption, sites were excluded from the calculations.

To calculate the net effect of a development scenario on the region's runoff and pollutant load, the runoff from the corresponding greenfield site must also be considered. This calculation is described in the section on "Comparisons of Brownfield and Conventional Scenarios" below.

Issues in the Application of L-THIA

The estimates of runoff and pollutant loads at the brownfield sites are based on the assumption that L-THIA is representative of conditions at these sites. However, brownfield sites may have different hydrologic properties than those of other infill sites or greenfields. Soils may be different than the original soils in the area. They may have been graded, compacted, or replaced or supplemented with fill brought in from elsewhere and they may contain high concentrations of pollutants. If fill has been used, permeability may be increased. If the cleanup included a protective cover, permeability may be reduced and runoff would be elevated. L-THIA was not designed to address these special conditions. The runoff and pollutant load estimates based on L-THIA do not consider situations that have these unusual hydrologic effects. The model is meant to represent "typical" urban situations. Accounting for this pollutant reduction would require more site-specific data that are not readily available, such as runoff, pollutant concentrations, and percent of a site that is impervious. Thus, although L-THIA provides a broad approximation adequate for a comparative analysis of this sort, it may over- or under-estimate runoff values.

One result of this limitation is that the estimates of stormwater runoff impacts do not consider the contribution to pollution reduction resulting from the *cleanup* of the brownfield sites. To the extent that heavy contamination at a site that produced high pollutant loadings had been cleaned up, the benefits (reduction in pollutant loads) due to the cleanup is not considered in this analysis. On the other hand, this factor is mitigated by the fact that many brownfield sites actually require little or no cleanup. The estimated values should be considered as reductions in runoff due to the development, which usually occurs after cleanup.

Pollutant loads, as well as runoff water quantity, also can be affected by the application of stormwater best management practices (BMPs) at a site. A number of these BMPs (e.g., detention and retention basins, infiltration basins and trenches, porous pavement, native landscaping, and green roofs) can be applied to individual properties and developments. The version of the L-THIA model used does not consider BMPs in its algorithms. Adjustments to the estimates based on average performance characteristics of various BMP techniques were considered. However, information was not available regarding which types of BMPs might be employed at either the brownfield or hypothetical alternative locations.

The efficiency of BMPs in removing pollutants can vary widely with the type of BMP and site and rainfall characteristics. A number of sources indicate that BMP removal efficiencies can range from negligible to 100 percent of pollutants from runoff, depending on the site conditions and type of BMP employed (EPA undated and EPA 1993). Thus, it is possible that effective BMPs would reduce the significance of the brownfield-greenfield comparison. While BMPs could affect total loads, it is unclear whether considering BMPs would affect the percentage comparisons of the brownfields and their counterpart greenfield sites, since BMPs may be applied to both brownfield and greenfield sites. Given the greater acreage of the greenfield sites, there may be greater potential for benefits of BMPs at these sites than at developed brownfield sites. Quantitative analysis of the impact of BMPs was not conducted for this study. It is possible that BMPs will be a greater factor in current and future development, as smart growth practices become more common.

Alternative Conventional Development Scenario

The alternative scenario includes the locations where the same type of development would likely have been built if it had not been built on the brownfields, and estimates of the environmental performance indicators for these locations.

Identification of Alternative Conventional Locations

For each brownfield site, an alternative location was assigned using a methodology suggested in EPA guidance on applicable methodologies to account for the benefits of infill in state implementation plans (EPA 2001a). Methodology M2 of EPA's guidance calls for assigning development to the fastest growing parts of a planning region. Since brownfield sites are only a small portion of total development in the region, it is reasonable that the alternative development would generally follow this pattern. The development counterpart for each brownfield site was assigned to one of the top 10% (5% for Seattle) fastest growing traffic analysis zones (TAZs). The fastest growing TAZs were based on population and employment shifts in recent years, where the percentage of the regional population and employment for each TAZ experienced the greatest increase in population and employment with respect to all other TAZs. The high-growth areas are shown on maps included in Sections 2 through 6. Alternative locations for each brownfield were selected from among the high-growth employment areas and high-growth residential areas. Properties with uses that are economically linked primarily to residences were assigned according to the TAZs with the fastest growing population or housing stock. Properties whose activities are primarily linked to employment were assigned to the TAZs with the fastest growing employment. The use of a statistical location-selection procedure helped to ensure impartiality in the site-selection process.

Estimation of Alternative Conventional Development Size

Development generally consumes more acreage in suburban and rural areas than in more dense, urban areas, due to building form, parking requirements, and, typically, lower land cost. Therefore, the majority of the alternative locations would require more land than their brownfield counterparts. Based on a range of values derived from literature on land use patterns (Exhibit B-4), it was assumed that the alternative sites would generally require an average of two to four times the acreage of their brownfield counterparts. This range was considered reasonable, based on the best professional judgment of planners in the Seattle area (PSRC 2006). Judgments of local planners were not available for the other regions. Thus, an average acreage multiplier of two is used for a more conservative estimate and an average of four for an upper bound value. Considering that the objective of this study is to develop an approach that can be readily replicated in different regions, and potentially nation-wide, a simpler approach is warranted.

Land use decisions are inherently influenced by a number of site-specific factors, including specific type of land use, regional practices, and location within a region, such as inner or outer suburb or exurb. As a result, there is a wide variation in the amount of land consumed in similar uses in different areas, or even properties within close proximity. In many areas, land use is determined by overlapping jurisdictions, special exemptions, historical practices, and other factors that may cause developers to over- or under-comply with zoning densities. Reviewing zoning ordinances will not necessarily provide an accurate estimate of likely land consumption.

Exhibit B-4. Brownfield/Conventional Offset Ratios *

Source	Variable	Industrial	Commercial	Residential	Total/Average
J. P. Deason, et. al.	Mean	6.2	2.4	5.6	4.5
	Median	1.3	1.7	2.2	NA
	Range	0.5 - 60	0.5 - 13	0.4 - 46	NA
Burchell, R.W., et. al.	Mean	2 – 4	2 – 4	2 – 4	2 - 4
Best Professional Judgment for Seattle Area	Mean	2 - 4	2 - 4	1.6 – 4.5	1.6 – 4.5
Review of 12 studies (Appendix A)	Range				2 - 8

* Ratio of greenfield acreage to brownfield acreage typically used for the same use type and amount of development.

Sources & Notes:
Deason, J.P., et. al. 2001*. Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights, and Arial Differentials*. The estimates in this report are based on land use requirements in six urban areas, not on the study of actual projects. There is no knowledge as to whether developers over-complied or under-complied with the regulations. The study did, however, use a number of conservative assumptions when judgments were needed. Range and standard deviations were high.

Burchell, R.W. et, al., 2000. *Cost of Sprawl⊂2000*, Transit Cooperative Research Program (TCRP) Report 74. This study estimates land requirements for a given amount of non-residential and residential demand using typical floor area ratios (FARs) at the county level. Residential densities at the county level were derived from a combination of sources, including Census' Survey of Construction, Survey of New Mobile Home Placements, and Survey of Market Absorption, and information from the Urban Land Institute and the National Association of Home Builders. Based on historical county-level data, the study estimates that multifamily residential densities for the Pacific coast in urban areas/urban centers is 4.5 times the densities in undeveloped rural areas, 3.02 times rural city densities, and 1.6 times suburban center densities.

Professional judgments for Seattle area, based on communications with planners at the Puget Sound Regional Council (PSRC 2006).

Estimation of Impacts on Air Quality and Personal Vehicle Energy Consumption

Using information on the conventional development locations, acreage, and categories of use, the environmental characteristics of these locations were described in terms of the indicators listed in Exhibit B-2 for the brownfield sites.

Estimation of Impacts on Water Quality

For the purposes of stormwater modeling, all alternative sites were assumed to be greenfields. Using information on the alternative development locations, acreage, and categories of use (e.g., commercial, residential, agricultural), the stormwater runoff and pollutant loads for each greenfield location was estimated with the L-THIA model in a procedure identical to that described above for the brownfield sites. Since the precise location of a greenfield site within a TAZ or census tract was unknown, two land use categories were selected for each region. This approach allowed the calculation of a range of acceptable values based on highest and lowest likely runoff rates, rather than a single estimate. For example, for the Minneapolis region, it was assumed that the new construction would take place either in a former vacant agricultural or pasture area. These assumptions were based on the prevailing land use in the area and observation of Google Earth satellite images in the area of the TAZs.

The greenfield runoff values were also calculated for two different site sizes, which are described above in the subsection on air quality (2 x and 4 x the acreage of the corresponding brownfield). Thus, there are four different runoff values estimated for each undeveloped greenfield site and each developed greenfield site. These values were summed for each region. The algorithms used to calculate the final changes in runoff and pollutant load estimates are shown in the “Comparison” subsection.

The runoff estimates for the alternative locations did not include potential runoff from infrastructure needed to support the development, such as roads and utilities. Because most of the development in conventional development locations is less compact than at the brownfield sites, they typically require more road surface per capita than the brownfields. Thus, consideration of this factor would likely increase the estimated runoff resulting from the alternative conventional development scenario relative to the brownfield development scenario.

The estimate also may not have fully accounted for the differences in impervious area that may exist between brownfields and their counterpart alternative sites. It may be that the percent impervious area for greenfield sites is, on average, lower than that of their brownfield counterparts. This study found only three cases with clear empirical estimates. Based on these cases, the imperviousness of a greenfield site would be approximately 15-20% less than that of a corresponding brownfield property. Since this sample size is so limited, it was not used to adjust the estimates of runoff from the developed greenfields. However, these values formed the basis for a sensitivity analysis which provides an approximation of the magnitude of this effect.

L-THIA includes a fairly ample impervious area in its default settings (15% for commercial and 28% for industrial). Given these values, and the data from three previous studies, it is unlikely that the adjustment factor needed would be greater than the 10-20% range.

Using this range, an approximation was made of the impact on the delta runoff estimates provided in Sections 2 through 6. That is, the percent imperviousness for greenfield areas was reduced by 10-20% and the effect on the runoff estimates were estimated. This analysis was conducted for the Minneapolis-Saint Paul region. The results are that increasing imperviousness 10-20% would decrease the range of “impacts” (percentage decrease in runoff from greenfield development scenario to brownfield development scenario) from a reduction of 48-73% to 36-67% (Exhibit B-5). The reduction is nonlinear primarily because the runoff values for the brownfields in the equation on this page do not change with changes at the brownfields. That is, relative to the greenfield development scenario. The impact of this factor is greatest for agricultural lands, less for pasture and even less for forest.

$$\text{\% change} = \frac{\text{(Developed GF + undeveloped BF) - (Undeveloped GF + Developed BF)]}}{\text{(Developed GF + undeveloped BF)}}$$

Exhibit B-5. Impact of Imperviousness on Runoff Estimates

Delta Pervious Acreage (a)	Total Pervious Area (% of total parcel)	Percent Reduction of Runoff (BF-GF)/BF		
		Forest	Pasture	Agricultural Land
0% (b)	15-28%	62-73%	59-69%	48-56%
10%	25-38%	55-67%	51-62%	38-46%
20%	35-48%	54-65%	50-60%	36-44%

(a) increase in percent of greenfield acreage that is pervious relative to brownfields.
(b) Impervious values used for brownfields.

Comparison of Brownfield and Conventional Scenarios

The environmental performance measures for each site were compared and averaged for each region. The results were generally expressed in terms of percentage improvement of the brownfield site compared to its conventional/greenfield alternative on a per-capita basis or on a per-acre basis. For example, energy and emissions changes are expressed as the percentage reduction in personal vehicle energy use and emissions of carbon dioxide and air pollutants per capita that result from shifting development from greenfield to brownfield locations. Stormwater runoff was compared in terms of acre-feet and pollutants in appropriate metrics, such as pounds of pollutant.

Percent Change for Air Quality and Energy Measures

For the air quality and energy analysis, the results are expressed in terms of the percentage change from a conventional development scenario to a brownfield development scenario. For example, the change in vehicle miles traveled (VMT) is expressed as:

Change in VMT = (VMT C – VMT BF) / VMT C

Where,
VMT C = VMT per capita from a developed conventional scenario
VMT BF = VMT per capita from a developed brownfield scenario

% Change in VMT = (VMT C – VMT BF) / VMT C x 100

This expression calculates the percent reduction in VMT from shifting an equal amount of employees and residents from the prevailing practices in conventional development areas to brownfield areas.

Alternative VMT Comparisons

To test the sensitivity of the estimates derived by this method, a variation of EPA's Method M2 (EPA 2001a) was implemented. In this analysis, the average total VMT for the top 10% high-growth TAZs was compared to the average for the brownfields (average brownfield total VMT/average top 10% high-growth TAZs) (Exhibit B-6). Data were available for only three of the five cities (Seattle, Baltimore, and Emeryville). Using this method, the estimated VMT differences were an average of 9% greater than those of the primary method. Reductions in VMT under Method B are larger than under Method A because the average VMT of the fastest growing 10% of TAZs is greater than that of the statistically-selected TAZs. These estimates are not inconsistent with the results of the first calculation method.

Table B-6. Comparison of VMT Estimates

Region	% VMT Reduction Method A (a)	Method B (b)	% Difference (B1-B2)/B1
Seattle	57%	58%	2%
Minneapolis	32%	No data	No data
Emeryville	49%	51%	4%
Baltimore	42%	51%	21%
Dallas	53%	No data	No data
Average	49%	53%	9%
Range	42-57%	51-58%	2-21%

(a) From Table 1-1, based on EPA's Method M2 (EPA 2001a).
(b) Method 2 = Total VMT decrease from the average of 10% fastest growing TAZ, a variant of EPA's M2

Percent Change for Water Quality Impacts

The water quality comparisons follows the same basic rationale as the air quality analysis, but must also consider the runoff that continues at the brownfield site and the change in runoff due to the redevelopment at the brownfield site, even if the alternative site is developed instead. The delta runoff is divided by the total amount of runoff from both the developed brownfields and undeveloped greenfield alternatives. To obtain the net change in runoff for the entire region, the changes in runoff due to the development at the brownfield sites need to be factored in, which is done with the following algorithm:

A = Runoff occurring if greenfield were developed = (Developed GF + undeveloped BF)

B = Runoff occurring if brownfield were developed = (Undeveloped GF + Developed BF)

The percentage change (relative to greenfield development) =

$$= \frac{(\text{Developed GF} + \text{Undeveloped BF}) - (\text{Undeveloped GF} + \text{Developed BF})]}{(\text{Developed GF} + \text{Undeveloped BF})} \quad (1)$$

The denominator represents the total amount of runoff that would exist if the brownfield were not developed. This ratio was calculated for four scenarios for the greenfield locations: For example, in the Twin Cities area, when the greenfield is pasture at the lower acreage estimate (2 x the brownfield size), pasture at the higher acreage estimate (4 x the brownfield size), agricultural land with a lower acreage estimate, and agricultural land at the higher acreage estimate.

Alternative Stormwater Comparisons

In addition to the comprehensive calculation of regional net impacts, other ways of comparing the environmental performance of brownfields and infill development with greenfield development were considered . One method is to compare runoff and pollutant load of a developed and undeveloped greenfield, without considering runoff at the brownfield. The calculation is:

Percentage change (relative to greenfield development) =

$$= \frac{(\text{Developed GF runoff}) - (\text{Undeveloped GF runoff})}{(\text{Developed GF runoff})} \quad (2)$$

Because this approach does not incorporate runoff occurring at the brownfields, it tends to estimate greater percentage reductions in runoff than the previous algorithm. It provides a picture of the changes in greenfield areas, and does not address the brownfield areas. Although this value may be of interest to local planners, it does not fully capture the net change in runoff for the region. Exhibit B-7 compares the estimates of runoff developed from the two approaches.

Exhibit B-7. Comparison of Alternative Estimates of Change in Stormwater Runoff

Region	Delta Brownfield / Undeveloped Brownfield (%)	Delta Greenfield / Developed Greenfield (%)	Comprehensive Algorithm (Includes Both Brownfield and Greenfield Values) (a)
Seattle	- 3.5%	-76 to -82%	-49 to -64%
Minneapolis-St. Paul	- 0.6%	-67 to -82%	-48 to -69%
Emeryville	6.2%	-44 to -65%	-27 to -45%
Baltimore	Unknown	-71 to -87%	-48 to -70%
Dallas-Ft. Worth	-2.7%	-47 to -72%	-32 to -52%

(a) From Exhibit 1-2

Limitations of the Analysis

General

- There is no way to completely ensure that double counting of benefits does not occur. Because brownfields development may replace other infill projects, it would be appropriate to estimate the magnitude of this replacement and adjust any estimate of gross benefits by this amount, thereby determining the net benefits. Some previous studies accounted for this factor by adjusting the benefits down by some factor such as 10-20%. To some extent, the methodology used in this study accounts for this type of double counting because it statistically allocates the hypothetical alternative development among the fast-growing TAZs, regardless of the TAZs' location within the multi-county planning area. In fact, a few of the alternative sites were located in downtown areas and others just outside city limits.
- In selecting the alternative growth locations, this study did not inventory the neighborhoods with respect to their development potential. Such an inventory would help identify undeveloped or underdeveloped land, including infill and greenfield sites, that are available to absorb development and that do not have environmental or zoning restrictions that would preclude development. Although the locations were selected statistically, which helped to ensure that the process was impartial, there is always the possibility that one or more of the locations selected would not be a feasible or practical development site. If this methodology were expanded to many other metropolitan areas, it would be impractical to obtain reviews of the relevant local planners.
- Implicit in this analysis is the assumption that a number of factors that can substantially affect land use over long periods of time will remain unchanged. Examples of these factors include land use policy (e.g., zoning, environmental regulations), transportation policy (e.g., parking or toll pricing), transportation infrastructure (e.g., roads, bridges, and transit), economic conditions, and

demographic characteristics. This assumption is justified because the analysis will be applied to known EPA-assisted brownfield redevelopment sites, and these sites are a relatively small part of the total development activity in a metropolitan area. However, if a municipal area should undergo significant changes in any of these factors, or should brownfields development become a larger part of the regional economy, this assumption would need to be revisited.

- The data used in this study do not, for the most part, reflect the potential impacts of new urban designs. These designs include strategies such as compact, mixed-use, and transit oriented development and are occurring in outlying as well as urban areas. This type of development has the potential to improve the environmental footprint of some outlying areas as well as infill areas. It is unclear to what extent these developments would alter the results of this study. In addition, the implementation of this type of development is not universal. Much, but not all, of the data used in this study predates many of these projects.
- As a result of smart growth implementation, many strategies are available to help achieve environmentally responsible development, whether on a brownfield or a conventional site. These strategies, which can include urban design, efficient transportation, stormwater BMPs, and green building techniques, can be considered when planning and implementing intensive development programs. Even though the environmental footprint of development in both urban areas and outer-ring suburban areas may be improving, it is likely that development in urban areas will continue to have a better environmental footprint, especially for transportation-related measures, because of the relatively superior location efficiencies of most infill areas.

Air Quality

- There are differences in how MPO's estimate VMT, but they are not likely to significantly affect the outcome of this study. The primary comparisons in the study are between brownfield and alternative conventional sites within each region. The same MPO tabulated the estimates used for both brownfield and conventional locations, so the comparisons are valid.
- The analysis did not quantify the potential for very localized high concentrations of pollutants that may occur due to high development or activity in any specific area. High concentrations of some of these pollutants, such as nitrogen oxides, carbon monoxide, and volatile organic compounds, can lead to increased health risks or cause an area to fall out of compliance with air quality attainment goals. High concentrations can occur in a specific location even though the total emissions for the region have declined or remained unchanged. Only one site out of the 163 sites in the dataset may have potential for generating an amount of commercial traffic large enough to cause significantly elevated levels of these pollutants to be of concern to a neighborhood. This 20-acre property, which is not yet fully built out, may generate large amounts of heavy truck traffic as a result of a new warehouse and distribution center. Despite this potential hot spot, the brownfields development results in a reduction of these emissions for the entire region.

Water Quality

- The estimates of stormwater runoff and pollutant loads may understate or overstate the full amount of the benefit of brownfields cleanup and redevelopment, because the L-THIA stormwater management model does not consider unusual conditions that may exist at a brownfield site that can have hydrologic effects. Examples of such effects include heavy pollution, extremely compacted or graded soil, or a site built on fill brought in from elsewhere. The model is meant to represent "typical" urban situations, not necessarily sites with unusual conditions.

- Following from the previous point, the estimates of stormwater runoff benefits do not consider the contribution to pollution reduction resulting from the *cleanup* of the brownfield sites, which may contribute to an underestimate of the full amount of differences between the brownfields and their greenfield counterparts. However, since many brownfield sites actually require little or no cleanup, this difference may or may not be significant.
- The stormwater runoff analysis did not incorporate estimates of the potential impacts of stormwater best management practices (BMPs). Information on the types of BMPs used, if any, at the brownfield sites or at the hypothetical greenfield sites was not available. The efficiency of BMPs in removing pollutants can vary widely with the type of BMP, site characteristics, and precipitation profile. A number of sources indicate that BMPs can remove anywhere from negligible amounts to 100 percent of pollutants from runoff, depending on the site conditions and type of BMP employed (EPA 2009 and EPA 1993). Thus, it is possible that effective BMPs would minimize the significance of the brownfield-greenfield comparison. While BMPs could affect total loads, it is unclear whether considering BMPs would affect the percentage comparisons of the brownfields and their counterpart greenfield sites, since BMPs may be applied to both brownfield and greenfield sites. In some situations, the potential for benefits from BMPs may be greater for the greenfield sites, because the volume of stormwater is much greater (due to the greater size of the average greenfield site relative to the brownfield).
- The stormwater runoff estimates do not allow for potential differences in the percent imperviousness of a site between brownfield sites and their greenfield counterparts. This limitation is due to a lack of information with which to estimate percent imperviousness for the study sites. A simulation using assumed values based on a limited number of case studies, indicated that the benefits would be reduced somewhat, but would still be substantial.
- This study did not account for the stormwater runoff associated with infrastructure, such as roads and utilities. Infrastructure needed to support brownfields development generally requires less land per capita and results in less runoff than infrastructure needed to support a similar amount and type of development on conventional sites. Generally, the lower the population density, the more road and highway surface is called for to connect the many trip origin and destination points. Fewer lane-miles implies less road surface and, consequently, lower stormwater runoff.

The methods used in this study have provided approximations of the level of environmental parameters which are not considered precise enough for regulatory proceedings, such as air quality planning submissions. However, they appear to provide a good indication of the relative environmental performance of brownfield versus conventional sites of the same use type.

Acronyms and Abbreviations

Acronyms

Ac	Acre
ACRES	Assessment, Cleanup and Redevelopment Exchange System
BMP	Best management practice
BOD	Biological oxygen demand
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DU	Dwelling unit
ECOSS	Environmental Coalition of South Seattle
HC	Hydrocarbon
HH	Household
INDEX	A geographical information system (GIS)-based planning support analytical tool
L-THIA	Long-Term Hydrologic Impact Assessment, a stormwater management model maintained by Purdue University
MPO	Metropolitan planning organization
MMBtu	Millions of British thermal units
NOx	Nitrogen oxides
PSRC	Puget Sound Regional Council
SOV	Single occupancy vehicle
SS	Suspended solids
SWMM	Storm Water Management Model
TAZ	Traffic analysis zone, travel analysis zone or similar designation. Also referred to as a travel survey zone in some regions
TSS	Total suspended solids
VMT	Vehicle miles traveled
VT	Vehicle trips

Accessibility Metrics

Jobs-to-housing balance	Total number of jobs divided by the number of dwelling units
% total region HH w/in 10 min. walk from TAZ center	Percent of households in the region within a 10 minute walk from the TAZ center along pedestrian routes
% total region HH w/in 30 min. transit ride from TAZ center	Percent of households in the region within a 30 minute transit ride from the TAZ center including walk time to the transit stop and travel time
% total region HH w/in 6 mi. by SOV from TAZ center	Percent of households in the region within a 6-mile drive from the TAZ center
% total region empls w/in 10 min. walk from TAZ center	Percent of jobs in the region within a 10 minute walk from the TAZ center along pedestrian routes

% total region empls w/in 30 min. transit ride from TAZ center	Percent of jobs in the region within a 30 minute transit ride from the TAZ center including walk time to the transit stop and travel time
% total region empls w/in 6 mi. by SOV from TAZ center	Percent of households in the region within a 6 mile drive from the TAZ center
Transit adjacency to employment	Percent of employment in a TAZ within ¼-mile of the TAZ center
Transit adjacency to housing	Percent of housing in a TAZ within ¼-mile of the TAZ center

Travel Activity

Home based vehicle miles traveled	Average vehicles miles traveled per resident produced during trips either originating or ending at home
Home based vehicle trips	Average number of vehicle trips per resident either originating or ending at home
Non-home-based vehicle miles traveled	Average vehicles miles traveled per employee produced during trips neither beginning nor ending at home
Non-home based vehicle trips	Average number of vehicle trips per employee neither beginning nor ending at home
Personal vehicle energy use	Annual MMBtu per capita for home based residential vehicle energy use and the annual MMBtu per employee for non-home based vehicle energy use
Total vehicle miles traveled	The sum of the average home based vehicle miles traveled per resident and the average non-home based vehicle miles traveled per employee
Total vehicle trips	The sum of the average number of home based vehicle trips per resident and the average number of non-home based vehicle trips per employee

General Terms

Brownfield	EPA defines "brownfield site" as real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant
Dwelling density	Dwelling units per gross acre
Employment density	Employees per gross acre

Greenfield	Parcel of land that is previously undeveloped, except perhaps for agriculture
Gross acre	An actual acre consisting of 43,560 square feet, including the development footprint and non-buildable land
Infill	The use of vacant land and property within a built-up area for further construction or development
Pop	Population
Population density	Number of residents per gross acre
Residential structural energy use	Annual millions of British thermal units (MMBtu) per capita for residential structural energy use
Travel demand model	A computerized model used by transportation and other planners to simulate travel patterns in a region

U.S. Environmental Protection Agency
Air and Water Impacts of Brownfields
Redevelopment: A Study of Five Communities

Solid Waste
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EPA-560-F-10-232
April 2011
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