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Land Use: A Powerful Determinant of Sustainable & Healthy Communities

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PROJECT COORDINATOR'S NOTE

I want to recognize the quality of effort extended by the authors. Ordinarily, one might despair of the prospects of success when 19 individuals from 9 separate organizational units are asked to address a diffuse body of knowledge such as "Land Use."

In this report, the reader will find the remarkable result of an extraordinary effort by a dedicated interdisciplinary group of EPA scientists who distilled useful principles and guidance from a vast and scattered literature. Future investigators will have the benefit of access to a searchable database of over 1400 references created by the authors.

It was an enriching experience to work with this group and find within it a meaningful summary of the state of the science. Barbara Walton, Project and Task Lead, September 30, 2013

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LIST OF ABBREVIATIONS

ADD	Attention deficit disorder
BMI	Body mass index
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CO2	Carbon dioxide
CBD	Central Business District
DPSIR	Drivers -pressure-state-impact-response framework
EPA	U. S. Environmental Protection Agency
EQI	Environmental Quality Index
ERS	Economic Research Service
GHG	Greenhouse gas emissions
GIS	Geographic information systems
HIA	Health impact assessment
IOAA	Immediate Office of the Assistant Administrator
IUWM	Integrated urban water management
LID	Low impact development
NCEA	National Center for Environmental Assessment
NCER	National Center for Environmental Research
NEPA	National Environmental Policy Act
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Laboratory
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
ORISE	Oak Ridge Institute for Science and Education
SES	Socio-Economic Status
SHC	Sustainable and Healthy Communities
TRI	Toxics release inventory
U.K.	United Kingdom
U.S.	United States
VMT	Vehicle miles traveled

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EXECUTIVE SUMMARY

Land Use : A Powerful Determinant of Sustainable & Healthy Communities

- "Land Use: A Powerful Determinant of Sustainable and Healthy Communities" is a report prepared by the 2013 Land Use Team to fulfill the 2013 SHC Product 4.1.2 described as "A synthesis of current practices for land use decisions in the built and natural environments, including current tools, trends, and research based on the peer-reviewed literature."
- A bibliography of >1400 peer-reviewed publications on land use was compiled, read and evaluated by the SHC 4.1.2 Land Use Team. These resources were entered in a searchable electronic EndNoteWeb© Land Use library that is currently available to EPA employees at no charge under an EPA license with Reuters.
- Land use has figured prominently in the history of the U.S. Environmental Protection Agency (EPA) and in the history of environmental protection in the United States. Today, municipal governments are the most influential arbiters of land use. Local polices and ordinances remain one of the most effective means to protect and restore natural ecosystems and undeveloped land.
- EPA's role as a leader in sustainability has evolved over the decades, continually reshaped through federal policies and priorities, standard setting, official guidance, and direct technical assistance to communities. EPA scientists and engineers have contributed to the published literature in the rapidly maturing discipline of sustainability.
- From a systems perspective, land is critically important as the source of natural capital that supplies materials (biomass, fuels, food, and water) and ecological services to the economic and public sectors of communities.
- An analysis of megatrends for population growth, economic development, and potential impacts on public health and the environment implicate land use as a principle factor in achieving a balance between sometimes competing demands for economic development versus protection of public health and the environment.

Megatrends in Land Use

- An analysis of megatrends for population growth, economic development, and potential impacts on public health and the environment, implicate land use as a principle factor in achieving a balance between sometimes competing demands for economic development versus protection of public health and the environment.
- From a systems perspective, land is critically important as the source of natural capital that supplies materials (biomass, fuels, food, and water) and ecological services to the economic and public sectors of communities.

- EPA's role as a leader in sustainability has evolved over the decades, continually reshaped through federal policies and priorities, standard setting, official guidance, and direct technical assistance to communities. EPA scientists and engineers have contributed to the published literature in the rapidly maturing discipline of sustainability.
- Urban sprawl, emerged during a period of rapid economic expansion and population explosion following World War II and remains the predominant form of growth in metropolitan areas.
- "Suburbia" appeared as a new landscape pattern co-incident with a major demographic shift of more affluent, professional workers and their families moved away from urban neighborhoods. Remaining properties lost and a downward sociological spiral took hold that caused many cities to spawn a phenomenon of inner city decay known, at its worst, as "urban blight."
- Land conversion in the United States is expected to increase the percent of developed urban land from 3.1% to 8.1% by 2050, consuming a significant amount of forest and cropland. Researchers have estimated that 18.8 million acres of land would be used to build 26.5 million new housing units as well as 26.5 billion square feet of new nonresidential space.

Influence of Land Use and Development Form on Sustainability and communities of the future

- Population loss, or shrinking towns and cities, is a longstanding concern in rural communities--nearly half of today's non-metropolitan counties lost population through net out migration over the past 20 years.
- Communities with declining populations, or "shrinking towns," face a contracting economy characterized by problems of unemployment and poverty, increasing demands for social services with fewer dollars to pay for them, an aging workforce, vacant properties, and a loss of historic structures.
- Attempts to compete with other jurisdictions for large economic development projects, such as new manufacturing plant, office parks, or regional big box retailers, may come at the expense of local businesses and the communities they aim to support.
- Moderately high population density is widely promoted by planners and smart growth advocates for its putative benefits, which include a smaller footprint of developed land, preservation of agricultural land and open space, less driving, more walking, support for transit systems, and greater opportunity for social interaction. Evidence supports many of these benefits.
- As urban residents travel to exurban areas for outdoor recreation, the demands placed on forest ecosystems in close proximity to growing urban centers pose challenges for natural resource managers. Another concern is that of human

safety when the public is brought in contact with wild life (bears, black bears, wolves, foxes, coyotes) poisonous plants and other hazards of the outdoors.

- Urbanization tendencies can be detrimental to wellbeing of lower income groups. “Gentrification,” the transformation of urban neighborhoods towards higher incomes and more expensive housing can marginalize lower income people.
- The American Planning Association (APA)recently reported findings of community priorities indicating job creation (70%) was at the top of the list, closely followed by safety (69%), schools (67%), protecting neighborhoods (64%), and water quality (62%). Bikeways (19%), walking trails (18%), and sprawl (16%) were often mentioned as high priorities.
- When asked to envision high priorities their ideal community, the most commonly cited elements were locally owned businesses nearby (55%),ability to stay in the same neighborhood while aging (54%), the availability of sidewalks (53%), energy-efficient homes (52%), transit (50%), and neighborhood parks (49%).
- Land use policies the permit development beyond the extent of water and sewer infrastructure increase the number of households that must rely on well water and septic systems. Increased use of septic systems raises the risk of sewage backflow and seepage into water delivery systems, increasing the opportunity for contamination of drinking water supplies that may undetected for long periods.
- Communities seeking to preserve agricultural land, whether for economic livelihoods, food security, or to maintain a rural aesthetic, have several options to manage land use. These include zoning policies, conservation measures, transfer of development rights, and use of compact development forms

Linkages: Environmental Protection, Federal Regulation, and Land Use Planning

- The Department of Interior and the U.S. Department of Agriculture both have major jurisdiction and responsibility for land use and preservation of natural resources
- The EPA has limited authority over private and public land use decisions; however, both regulatory and non-regulatory policies and practices of the EPA can have considerable impact on public health, natural resource management, environmental protection, and economic activity. EPA’s implementation of federal regulation for pollution control and prevention can all be of consequence for land management and land use practices. Thus, both legislative and non-legislative activities of the EPA can influence community decisions on land use.
- EPA collaboration with communities can help assure that environmental science and know how are marshaled to provide tools that communities can use to better inform their land use decisions. An additional consideration is that unless land use is afforded attention relative to its importance in shaping ecological and public

health, then many of the EPA goals for sustainability require downward revision or may simply become unachievable

- Urban sprawl has been identified as one of the most significant pressures leading to deforestation, loss of native habitats, reductions in the numbers and kinds of species—both flora and fauna—as well as loss of biodiversity in general.
- As populations, transportation networks, and appetites for affluence increase, the demand for land and the natural capital that it provides are subject to market forces of supply and demand. As land supply diminishes and demand increasse, the price of land will increase.

Megatrends in urban development

- Academic studies indicate that community priorities tend to be job creation (70%), followed closely by safety (69%), schools (67%), protecting neighborhoods (64%), and water quality (62%). Other priorities are bikeways (19%), walking trails (18%), and sprawl (16%.)
- "Suburbia" emerged as a new landscape pattern co-incident with a major demographic shift of the more affluent, professional workers and their families away from urban neighborhoods. Although sprawl was spawned during a period of exuberant economic expansion and population explosion following World War II, sprawl remains the predominant form of urban growth in major metropolitan areas today.
- Sprawl is not restricted to urban development; rural communities can also display both sprawling and compact development forms. Rural residents can just as easily be affected by the negative health impacts of an automobile-dependent development patterns.
- Another notable trend in U.S. populations is that 80 percent of the current US population lives in cities—this percentage is expected to continue increasing. Fifty percent of those in urban areas live in coastal environments. Sea-level rise and climate change can be expected to have a disproportionate displacement impact on these urban, coastal populations

What practices best support sustainable land use qualities?

- At the community level, active transportation (walkability), physical activity, health and social well being can be fostered by land use planning to include amenities of green space, parks, sidewalks, street trees and above all personal safety. Awareness of vulnerabilities to climate change and extreme heat events can promote sustainability as well as provision for affordable housing and other needs to protect vulnerable populations from disproportionate exposures.
- Regional scale land use quality most import for advancing sustainability include compact development patterns, affordable housing, and transportation that provides ready access to to jobs, wholesome food, financial and civic services,

and green space. Regional coordination to avoid unintended consequences from cumulative disadvantages of multiple small scale land use decisions.

- Recent and Planned Research products relevant TO Land Use Decisions and Sustainability.are summarized
- ORD products from all ACE, CSS, SHC and SSWR involve quantication of ecosystem goods and servies, analysis of human health impacts of land use decisions, and identification of thresholds and tipping points beyond the assimilative capacity of natural systems to recover from perturbation.
- Numerous indicators, indices, tools and models have been developed to measure, track, and mitigate the effects of land use changes to communities as well as to inform community decisions on land use to advance sustainability at the community level.
- Generation of alternative scenarios and collaborative approaches to community engagement on specific priorities and options comprise the ORD toolbox.

1 INTRODUCTION: THE U.S. ENVIRONMENTAL PROTECTION AGENCY, SUSTAINABILITY, AND LAND USE

Environmental Protection and EPA: Land use has figured prominently in the history of the U.S. Environmental Protection Agency (EPA) and in the history of environmental protection in the United States. This point was reinforced in speeches, editorials, and numerous papers presented in 2010 to commemorate the 40-year anniversary of the EPA (See Table 1) (Joseph Fiksel, Bakshi, Baral, Guerra, & DeQuervain, 2011) and to celebrate the agency's success in fulfilling its mission (Box 1).

Box 1. "The mission of EPA is to protect human health and the environment. . . by safeguarding the air we breathe, water we drink, and land on which we live . . ." *www.epa.gov*

Land conservation and land preservation represented the first systematic federal strategy to protect the environment for future generations. This 19th century approach was manifested in the establishment of national parks, federal lands, and national monuments. In the 20th century, environmental policy shifted to regulation of environmental contaminants in ambient media.

Creation of the EPA in 1970, coupled with passage of enabling legislation, established a new national paradigm to protect public health and the environment with emphasis decreasing the risks posed by toxic releases to air, water, and land.

This new regulatory approach put the federal government in partnership with the states: Compliance and enforcement of environmental regulations became the responsibility of the states once a state plan was approved by the EPA.

Sustainability and EPA: The mission statement of the EPA implies a commitment to principles of sustainability. The publication of "Our Common Future" (World Commission on Environment and Development, 1987)(See Box 2) strengthened this link through the participation of EPA Administrator William Ruckleshaus as a member of the Brundtland Commission and a co-author of "Our Common Future." Ruckelshaus's engagement gave EPA an early voice in calling out the inconsistency between visions of all people of all nations living well *versus* the reality of seemingly unbridled consumption of natural resources. The two concepts were incompatible.

EPA's role as a leader in sustainability has evolved over the decades, continually reshaped through federal policies and priorities, standard setting (e.g., Energy Star), official guidance, and direct technical assistance to communities. In addition, many EPA scientists and engineers have contributed to the published literature in the rapidly maturing discipline of sustainability (Grossarth & Hecht, 2007; A. Hecht, 2009; A. D. Hecht & Miller, 2010; Jordan & Benson, In preparation; Jordan & Summers, 2012; Sidle, Benson, Carriger, & Kamai, 2013).

	19th Century	20th Century	21st Century
Focus	Land conservation	Human health risk; media/site/ problem-specific	Complex regional/ global problems
Outcome	Land preservation	Pollution control; management of anthropocentric ecological risk	Global sustainable development
Principal Activity	Land/water regulation/simple contaminant controls	Compliance/remediation/ technological emphasis on problem solving	Integration of social, economic, and technological information for holistic problem solving
Economic Focus	Value of land use and industrial development	Cost minimization	Strategic investments/long-term societal well-being
Regulatory Activity	Low	Heavy	Flexible, including market-based incentives
Conceptual Model	Expansion vs. preservation	Command-and-control	Systems/life cycle approach
Disciplinary Approach	Disciplinary/insular	Multidisciplinary	Interdisciplinary/ integrative

Table 1 Two centuries of evolving U.S. Environmental Policy (Fiksel et al, 2011)

Sustainability and the Office of Research and Development: In 2010, the year of EPA's 40th anniversary, the Office of Research and Development (ORD) embarked on a major effort to consolidate and refocus research activities to address sustainability. This restructuring, led by EPA Assistant Administrator Paul Anastas (2009 to 2012), (see Box 3) was consistent with Executive Order 13514 on "Federal Sustainability."

The proposed transition from a risk assessment paradigm to one of sustainability was endorsed and reinforced by the National Research Council (NRC) in two reports: Sustainability in the US EPA (2011) and Sustainability for the Nation: Resource Connection and Governance Linkages (2013).

In restructuring the ORD research agenda, 17 multi-year plans were consolidated and refocused to create four Research Programs: "Air, Climate, and Energy" (ACE); "Chemical Safety and Sustainability "(CSS); "Safe and Sustainable Water Resources" (SSWR);

Box 2. Sustainable Development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." *Our Common Future*

"Sustainable and Healthy Communities" (SHC). Two additional focus areas were established to provide for "Human Health Risk Assessments" and "Homeland Security."

The concepts of *"sustainability"* and *"effective partnerships with EPA stakeholders"* became common themes throughout the ORD research programs. ORD cultivated a closer engagement with EPA partners and stakeholders to shape the research agenda.

Listening sessions were held for communities, regions, and program offices so that ORD could hear directly the problems faced by the regulated community and could see where ORD could provide science-based help (Walters, 2012). The input from stakeholders was used to define the problems addressed by the newly established research programs-- ACE, CSS, SHC, and SSWR.

Land Use in the Natural and Built Environments. As a result of feedback from the listening sessions, "Land Use: Natural and Built Environments" was identified by the Sustainable and Healthy Communities (SHC) Research Program as one of four priority areas that would become organizing concepts for creating science-based products, tools, and approaches targeted to community needs.

In addition to Land Use, the three other areas were identified as important to communities and to achieve sustainability goals. These additional areas are: "*Transportation*;" "*Buildings and Infrastructure*;" and "*Waste and Materials Management*." An ORD project lead was identified for each of these topic areas and teams were formed under the direction of the SHC National Program Director (NPD). These teams of researchers from the ORD Labs and Centers were tasked by the NPD to prepare white papers summarizing the published literature and critical resources for each team topic.

Box 3. "Sustainability is our true north. The work that we do – the research, the assessments, the policy development is part of ensuring we have a sustainable society; a sustainable civilization."

Paul Anastas, EPA Assistant Administrator, Office of Research and Development. Testimony before the U.S. House of Representatives, Committee on Science and Technology, March, 10, 2010.

1.1 Scope and Structure of the Land Use Report

This report is an analysis of the published literature on current land use practices, policies, and factors that influence sustainability of communities and ecosystems. Primary emphasis is on U.S. practices and policies at the community and neighborhood levels; however, state, regional, national and, occasionally, international practices are mentioned.

Contemporary land use decisions related to sustainability are described; trends and correlations involving land use and sustainability goals are addressed. Quantitative correlations from the published literature are noted when available.

Purpose of the Report: "Land Use: A Powerful Determinant of Sustainable and Healthy Communities" was produced by the 2013 Land Use Team to fulfill SHC Product 4.1.2 described as follows:

"A synthesis of current practices for land use decisions in the built and natural environments, including current tools, trends, and research based on the peer-reviewed literature."

The Land Use Team. The following individuals comprised the 2013 Land Use Team: Llael Cox, James Andrews, Nick Flanders, Verle Hansen, Ingrid Heilke, Scott Jacobs, Melissa McCullough, Tanya Moore, Devon Payne-Sturges, Brenda Rashleigh, Marilyn TenBrink, John Thomas, Claudia Walters, Barbara Walton, James Weaver, Yongping Yuan, Tina Yuen, and Anthony Zimmer.

All members of the team have advanced degrees and professional experience in key areas relevant to land use and environmental science. Areas of expertise represented on the Team were ecology (aquatic terrestrial, landscape, systems and agricultural ecology); engineering (agricultural; environmental, civil, and chemical engineering); public health, children's health, community programs ; human health assessments, risk assessments; hydrology; geology; statistics; city and regional planning; transportation; architecture; as well as federal and international environmental policy.

Team Approach: The Team members, who are EPA personnel located around the country, met by conference call once a week for much of 2013 to conduct this work. The conference calls averaged out to about once every 1 ½ weeks for the fiscal year. These meetings were used to review data, discuss findings, identify next steps and agree on individual assignments. A bibliography of the relevant literature was compiled by the group in an electronic EndNoteWeb© library available to EPA employees under an agency license with Reuters. These 1400+ references compiled in the EndNoteWeb© library served as the primary resource for this review (Appendix D].

Structure of the document. Information on land use is organized and presented for key issues related to sustainability. Generally accepted best practices, relevance of the findings to land use decisions, qualitative and quantitative correlations of cause and effect are summarized when available. Key areas where information is lacking are identified, as well as areas of contradiction or conflict based on the published literature. Unintended consequences of land use decisions are noted: speculations are identified as such. We conclude with a summary of the current state-of-practice for the topics covered and identify scientific research needs to support community decisions in support of sustainability at the community level.

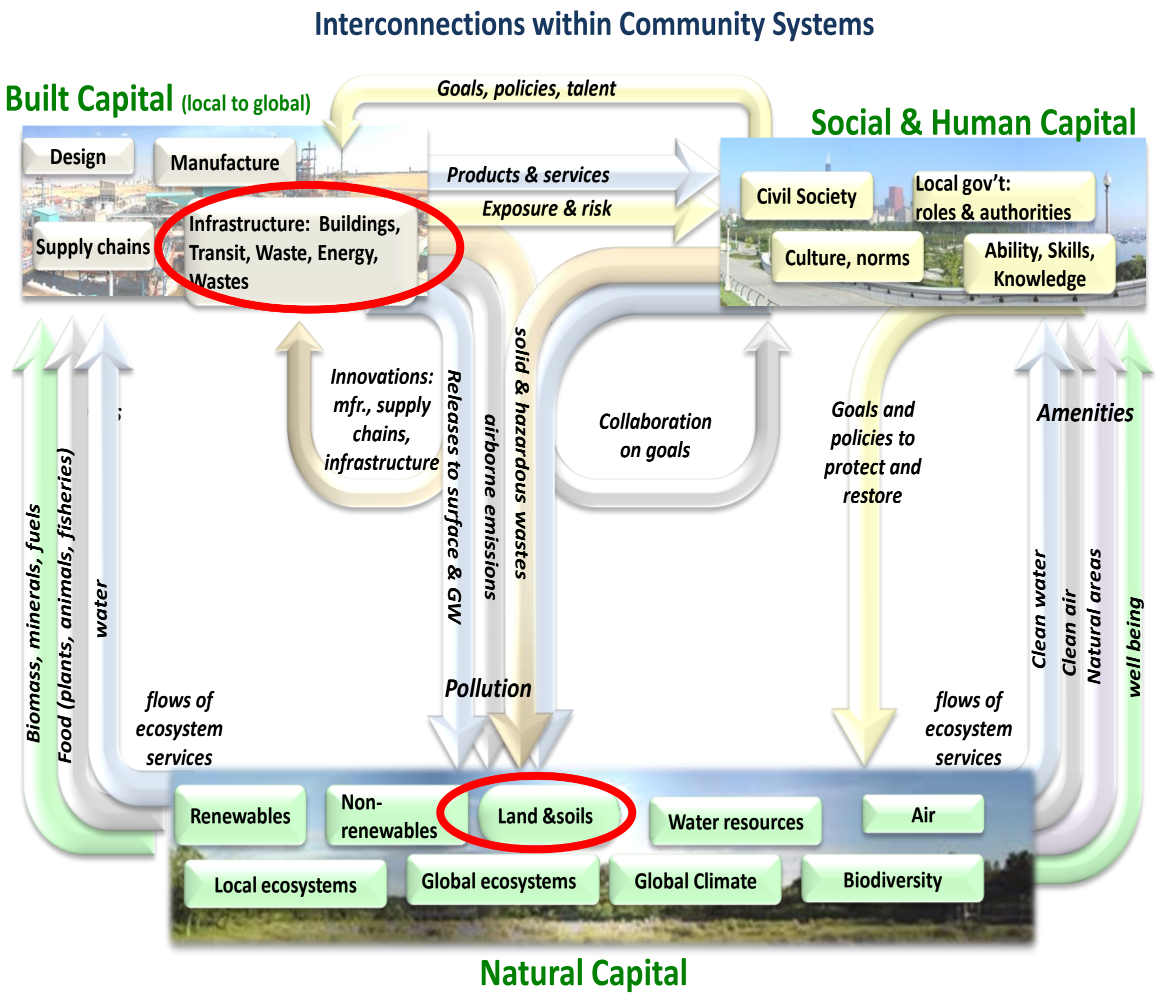
1.2 Land Use and Sustainability: A critical link

Land Use figures prominently—explicitly and implicitly—as a critical factor in achieving community sustainability goals (Claudia M. Agudelo-Vera, Mels, Keesman, & Rijnaarts, 2011; Kramer, 2013; Shaw, 1992) Labiosa, 2013) From a systems perspective, land is critically important as the source of natural capital that supplies materials (biomass, fuels, food, and water) to the economic and public sectors. In addition, ecosystems provide services and associated amenities, such as clean air, clean water, biodiversity, natural areas, and human well-being (Francis et al., 2012; Goldstein et al., 2012; Radeloff et al., 2012).

The conundrum faced by many communities comes when demands for available land conflict with the critical role of land use for sustaining essential ecological services, aesthetics, and healthful living conditions. We review several dimensions of land use that affect and are influenced by community decisions on land use.

A Systems Perspective on Land Use: The Triple Value Model (Figure 1) depicts a holistic, systems perspective of sustainability as flows of goods, services, and as well as pollutants such as solid and hazardous waste, air emissions, releases to surface and ground water (J. Fiksel, 2001; Hacking, 2008). The Triple Value Model was used by the Land Use Team as a general organizing framework to scope issues regarding Land Use.

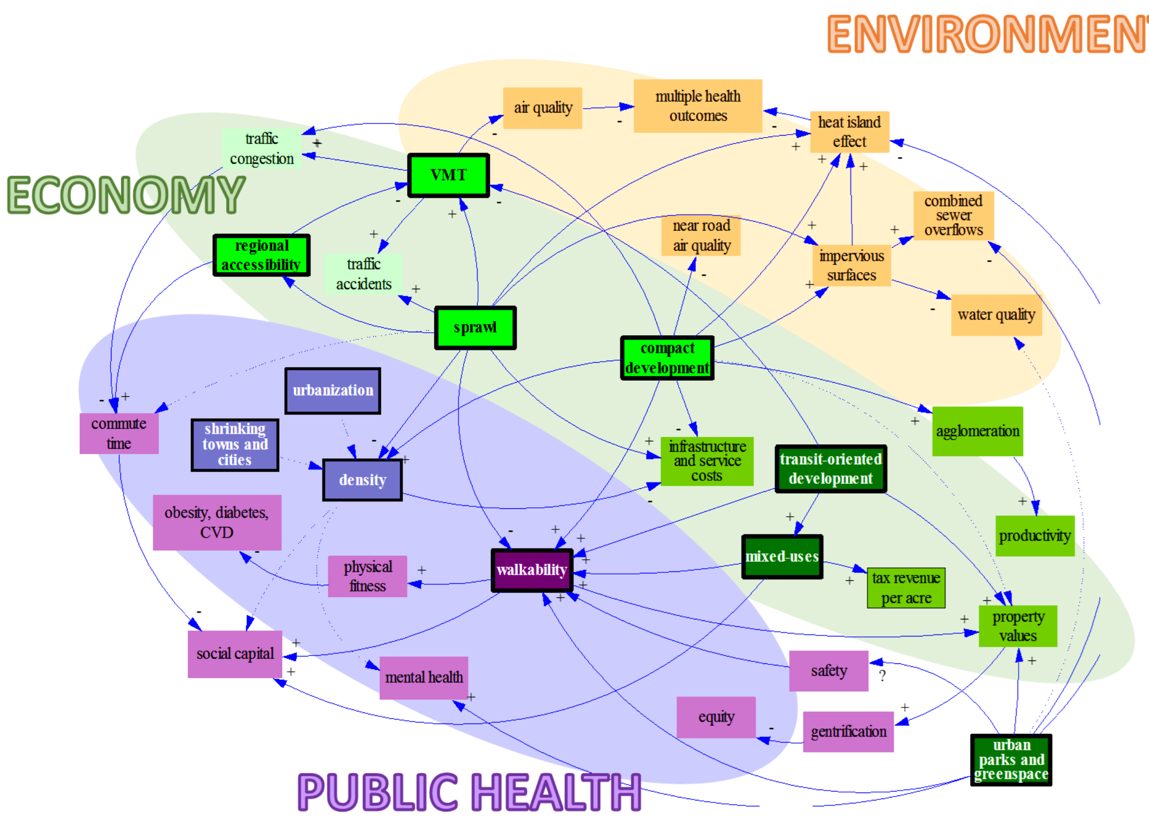
Figure 1 Schematic of the Triple Value Model



Schematic of the Triple Value Model (Joseph Fiksel, 2006) showing the role of Land (bottom center) as one of the sources of natural capital for the built environment, which includes Buildings, Transit, and Waste (upper left-hand corner). Land is also the recipient of Pollution from the built sector.

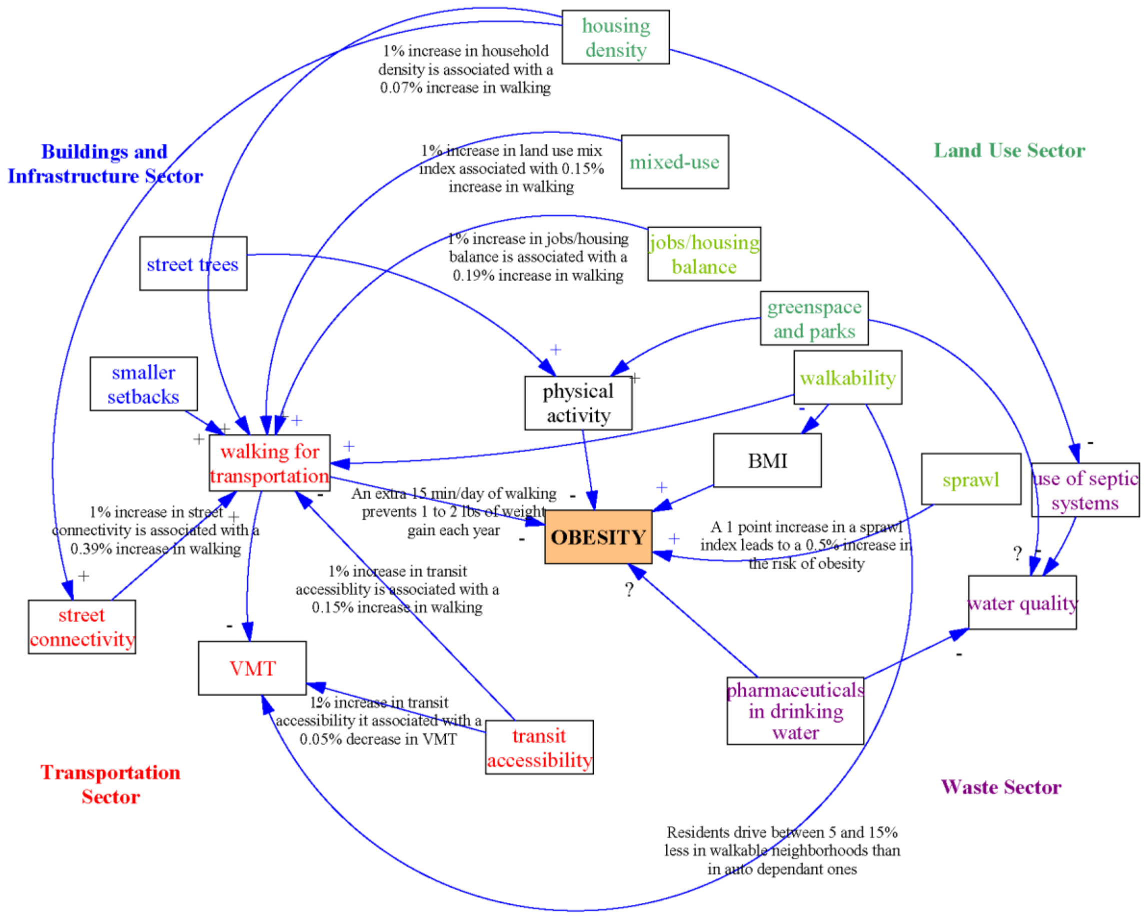
The schematic in Figure 2 illustrates the interconnectedness of the main topic areas addressed in this review. Legend: White boxes framed in black indicate the main topics (Drivers and States) addressed in the review. Boxes in orange, green, and purple indicate environment, economy, and public health relevance, respospectively.

Figure 2 Schematic of Main Topics addressed in this report showing interconnected ness in a Vensim type diagram. Relevance to pillars of sustainability are also depicted



Legend: White boxes framed in black indicate the main topics (Drivers and States) addressed in the review. Boxes in orange, green, and purple indicate environment, economy, and public health relevance, respospectively.

Figure 3 Schematic depicting obesity, an important community issue that involves all four sectors of the SHC to address. Sources: (Ewing and Cervero, 2010; Lovasi et al. 2011; Lopez, 2004; Kaczynski et al. 2008; Brown et al. 2009)



2 LINKAGES: ENVIRONMENTAL PROTECTION, FEDERAL REGULATION, AND LAND USE PLANNING

The Department of Interior and the U.S. Department of Agriculture both have major jurisdiction and responsibility for land use and preservation of natural resources. The Department of Interior includes the National Park Service, Bureau of Land Management, US Fish and Wildlife Service, Geological Survey, Bureau of Indian Affairs, Bureau of Reclamation; the U.S. Department of Agriculture includes the U.S. Forest Service.

The EPA has limited authority over private and public land use decisions; however, both regulatory and non-regulatory policies and practices of the EPA can have considerable impact on public health, natural resource management, environmental protection, and economic activity. EPA's implementation of federal regulation for pollution control and prevention, for example, the Resources Conservation and Recovery Act (RCRA), CERCLA, SARA, FIFRA, Clean Air Act, Safe Drinking Water Act and Amendments, the Clean Water Act, Brownfields Act (2002) can all be of consequence for land management and land use practices. Thus, both legislative and non-legislative activities of the EPA can influence community decisions on land use.

Local zoning ordinances can be instrumental as a means to achieve community goals for sustainability (Kopits, McConnell, & Miles, 2012; York & Munroe, 2010). Economic criteria, including costs and benefits, are important drivers for both environmental protection and land use. Decisions on land use and environmental protection are also relevant to the following responsibilities of EPA and communities alike: environmental justice (Baron et al., 2009; Nweke et al., 2011); adolescent and children's health (Acevedo-Garcia, Osypuk, McArdle, & Williams, 2008; Almanza, Jerrett, Dunton, Seto, & Pentz, 2012; Gordon-Larsen, McMurray, & Popkin, 2000; S. M. Wilson, Wilson, Heaney, & Cooper, 2007); market incentives (Carnoske et al., 2010); pollution monitoring (Karner, Eisinger, & Niemeier, 2010; Marshall, Brauer, & Frank, 2009); abatement, reclamation; economic valuation of benefits (Azqueta & Sotelsek, 2007; DiNapoli, 2010; T. A. Litman, 2003)

The complex interrelated elements of environmental protection, federal regulation, and land use planning constitute an importation reason for EPA to be informed of land use planning practices of communities as they seek to promote sustainability through their decisions. EPA collaboration with communities can be an effective means to ensure that environmental science and know how are marshaled to provide tools that communities can use to better inform their land use decisions. An additional consideration is that unless land use is afforded attention relative to its importance in shaping ecological and public health, then many of the EPA goals for sustainability may become unachievable or require downward revision.

Municipal Planning and the Role of Zoning. Nearly all land use decisions are made on the basis of economic criteria. Zoning is now the most widely used means to establish and enforce designated uses for land at the local level. Once the U.S. Supreme Court determined the constitutional validity of zoning in 1926 (Village of Euclid, Ohio, v. Ambler), zoning has become widely used across the United States to manage local land use. Zoning is routinely used to preserve desirable characteristics of neighborhoods as well as to proscribe unwanted or nuisance activities, (e.g., noise, livestock in residential areas, juxtaposition of bars to churches or schools, etc.). Zoning helps ensure that property values are preserved and tax revenues retained for the communities (Zellner et al., 2009). Zoning has also been implicated as a key contributor to some unanticipated consequences and discriminatory results of local land use decisions and ordinances (Maantay, 2001; Phillips & Goodstein, 2007; J. Schilling & Linton, 2005; S. M. Wilson, Heaney, & Wilson, 2010).

Urban sprawl. The proliferation of suburban communities that emerged after World War II was a key response to the growing demand for housing, privacy, and space. A rapidly multiplying population of young adults returning from war-time occupations intensified the demand for housing (Duany, Plater-Zyberk, & Speck, 2000). The impact of the baby boom, the interstate highway system, and growing appetites for material goods became the drivers for clusters of low-density housing at the perimeter of urban developments. These communities were dubbed “urban sprawl” or just plain “sprawl” (Danielsen, Lang, & Fulton, 1999; Duany, et al., 2000; R. Ewing, Pendall, & Chen, 2003a; Kunstler, 1993).

As the population, the economy, and highway travel increased, the impact on the land was often detrimental to the environment and the ecological services it provides (Knaap, Song, & Nedovic-Budic, 2007). Sprawl has been identified as one of the most significant pressures leading to deforestation (Manning, 2008), loss of native habitats, reductions in the numbers and kinds of species—both flora and fauna—as well as loss of biodiversity in general (Faeth, Bang, & Saari, 2011; Tewksbury et al., 2002). At the same time that the numbers of many native species are declining, undesirable nuisance or “weedy” species have emerged in geographic areas where not previously found and have become established as aggressive competitors for food, nesting space, and other resources (Pickett et al., 2011). These opportunistic, invasive species further accelerate the loss of biodiversity by outcompeting native species for habitat and food (Decker et al., 2012; Dolan, Moore, & Stephens, 2011; McKane et al., 2002). The conversion of agricultural lands and open space to developed use is also accelerating and has become a major factor changing the U.S. landscape from predominately rural to otherwise (Conway & Lathrop, 2005). Increasingly, farm land is converted to human needs for {Francis, 2012, Farmland conversion to non-agricultural uses in the US and Canada: current impacts and concerns for the future] for housing, transportation, raw materials for commerce and infrastructure, and to meet recreational needs (Francis, et al., 2012; Weber, Sloan, & Wolf, 2006).

2.1 Drivers of Land Use Decisions and Change

This DPSIR conceptual model (Figure 3) (Wolfslehner & Vacik, 2011) was embraced as a useful simplification of the complex and interrelated forces that influence Land Use decisions. Economics, infrastructure and social considerations are perceived as principle drivers at all scales of land use decision making — individual, community, county, state, regional and national.

Decisions on land use can have profound consequences—both positive and negative—subject of course to the views and values of those in the community served. For the purpose of this document, we evaluate consequences of land use decisions from the perspective of advancing an integrated economic, social, and environmental agenda to achieve sustainability objectives for the stakeholders involved.

Box 4. Urban and Coastal Populations

80 percent of the current US population lives in cities—this percentage is expected to continue increasing.

Fifty percent of those in urban areas live in coastal environments. From a long-term perspective, sea-level rise and climate change can be expected to have a disproportionate displacement impact on these urban, coastal populations.

Megatrends Affecting Land Use.

As populations, transportation networks, and appetites for affluence increase, the demand for land and the natural capital that it provides are subject to market forces of supply and demand. In addition to market forces, government and municipal policies can intervene, for example, to protect and restore natural areas (Crossman, Bryan, & King, 2009; Goldstein, et al., 2012; Kunstler, 1993).

Demands for housing, transportation, and natural resources constitute key drivers for ownership and access to land. Food and water, infrastructure, commerce, recreation, waste disposal plus less tangible needs inherent in cultural and religious practices, aesthetics, and spirituality —all contribute to the demand for land and access to land. (Bryan, Grandgirard, & Ward, 2009; R. W. Burchell & Mukherji, 2003; C. J. Dawkins & Nelson, 2002; R. Ewing, Cervero, & Trb, 2001). Pride of ownership and social status can also be motivators to acquire land (R. Bennett, Tambuwala, Rajabifard, Wallace, & Williamson, 2013; ERS, 2012b).

Impact of Population Growth on Demand for Land. The impact of U.S. population growth on future demand for land is potentially huge. Moreover, fast growth alone is associated with poor economic performance (Fan, Wang, Qiu, & Wang, 2009; Annemarie Schneider, Woodcock, Schneider, & Woodcock, 2008). In a study of the 100 largest U.S. metropolitan areas prosperity was found to be inversely related to growth (L. M. A. Bettencourt & West, 2011; Fodor, 2012). Faster growth rates were associated with lower incomes, greater income declines, and higher poverty rates. Unemployment rates tend to be higher in faster growing areas. The 25 slowest growing metro areas outperformed the 25 fastest growing in every category including per capita income. People in the mature (slowest growing) metro areas earned an average of $8,455 more in per capita personal income in 2009 (ibid).

Another notable trend is that 80 percent of the current US population lives in cities—this percentage is expected to continue increasing (Pickett, et al., 2011). Fifty percent of those in urban areas live in coastal environments (Box 4). From a long-term perspective, sea-level rise and climate change can be expected to have a disproportionate displacement impact on these urban, coastal populations (Barbier, Georgiou, Enchelmeyer, & Reed, 2013; Boruff, Emrich, & Cutter, 2005; National Resource Council, 2013; SiadatMousavi, Jose, Stone, & Ieee, 2009; Sidle, et al., 2013).

The growing human population will increase demand for land. The world population, currently estimated at seven billion, is anticipated to reach nine billion by 2050 U.S. Census Bureau (2012). The estimates for the U.S. population in 2050 differ, yet the magnitude of increase is around 100 million (Box 5). The inevitable consequence of rapidly increasing populations is a growing demand for housing, food, transportation. At the same time waste generation will increase. Satisfying human needs will mean a greater demand for land, resulting in diminishing supply and increasing prices.

Workarounds and modifications to reduce or accommodate the demand for land and space. Because land is a natural resource subject to intense and intensifying demand, a sustainability imperative calls for substitutes, innovative workarounds, and novel approaches to lessen demand for land and the services it provides. Examples of positive technology impacts include increased food supply through improved agricultural practices, crop improvement to achieve increase yields, more effective and efficient pest control. Other trends have been the emergence of urban gardens, compact development, combinations of residential and commercial uses, and greater reliance on vertical structures to create more space.

Box 5. Population Growth:

The U.S. population, currently estimated at 316 million, is projected to increase by 100 million by 2050. (US Department of Commerce, Census Bureau, June 14, 2013).

The U.S. population is projected to grow 42 percent between 2010 and 2050, from 310 million to 439 million (Vincent and Velkoff 2010).

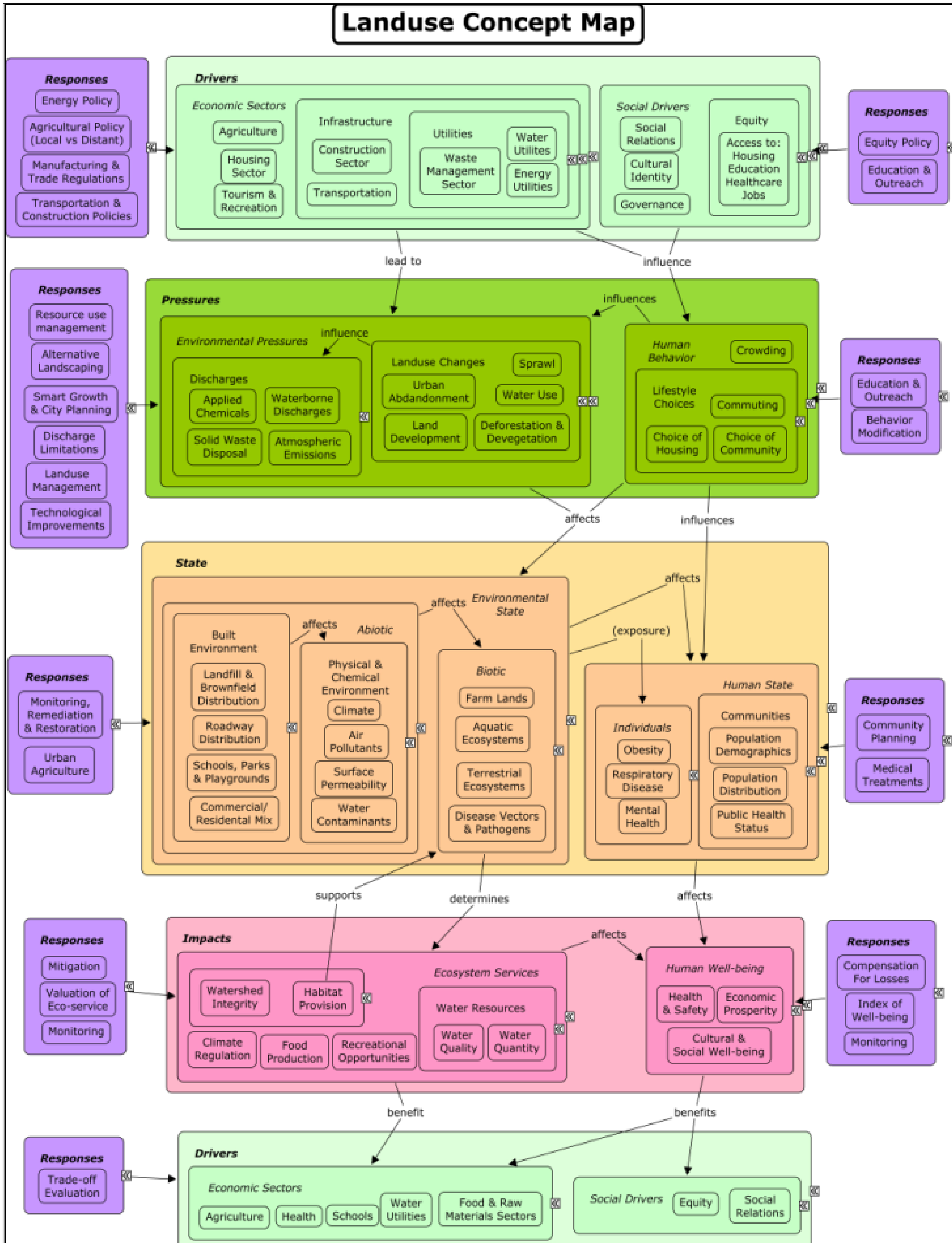
All of these changes represent ways to use land more efficiently to meet ever growing demands for space A variety of urban energy and water harvesting techniques were found to have the potential to cover up to 100% of electricity demand, 55% of heat demand, and 52% of tap water demand in the Netherlands (C. M. Agudelo-Vera, Leduc, Mels, & Rijnaarts, 2012). At the same time, innovative technologies can have unintended consequences, including health impacts, disproportionate exposures, inequitable division of benefits, or exacerbation of related issues.

Financial and Legal Forces. No matter who makes specific land use decisions, financial and legal considerations are foremost considerations (Bryan, et al., 2009; Goldstein, et al., 2012; Keeney, 2006; Terrapin Bright Green, 2012). Financial considerations may include the price of land, return on investment, time to recovery of investment, amount and duration of indebtedness incurred, cost of servicing debt, maintenance costs, cash flow limitations, taxes, and investment risk (speculation). Legal considerations are likely to apply to intended purpose and may involve federal regulations or restrictions by states, municipalities, zoning ordinances, design standards, and building codes. Yet another factor in land use decisions can be the indirect impact of infrastructure investments, fiscal policy, and other state and local policies that can shape future development patterns.

Stakeholder Preference and Acceptance. The scope and scale of financial and legal factors differ across commercial (business), public (federal, state, municipal), and private (individual, household, religious) interests. A decision maker's allegiance to or affiliation with any of these groups is likely to influence values, priorities, and the sense of responsibilities among decision makers. The fact that decision makers, as individuals, may belong to multiple interest groups adds to the complexity and richness of issues that shape land use decisions. Major categories of interest groups are the following:

- **Commercial (business)**
    - Producers of the built environment—developers, architecture and engineering firms, construction firms
    - Consumers of the built environment—all firms that own or lease commercial buildings or industrial facilities
- **Public (governmental)**
    - Scales - Federal and state government, regional agencies, local government
    - Levels of Decision Authority – Professional Staff, Appointed Volunteers, Elected Officials
- **Private (individuals, households, clubs, places of worship)**
    - Home owners, renters, Community Development Corporations (CDCs),
    - Social clubs
    - Churches, synagogues

Figure 4 Land Use DPSIR



Issues Faced by Decision Makers

- How can choices for land use affect favorable outcomes for achieving sustainability goals?
- What scientific information or insights will inform decisions beyond what is provided by the commercial and private sectors?
- How can scientific know-how from the US EPA augment and support the complex economic, public health, and environmental considerations of the various interest groups without replicating the efforts of trade associations, professional societies, municipalities, academia, or private enterprise?
- Are there non-regulatory actions or practices that can strengthen the economy, protect public health, and still safeguard the natural environment?

Guidelines and Resources for Land Use Decision makers

In general, public and commercial land use decisions are guided by written policies or plans developed to steer decisions in favor of valued outcomes. Such guidance takes many forms. Most common are the following:

- *Comprehensive plans.* These can be long range or near term and are commonly directed to state, regional, and local scales.
- *Fiscal programming.* Use of spending authorities such as capital plans and annual budgets, are effective as driving forces for land use decisions
- *Formal policies.* These can take the form of federal, state, or local regulations, fiscal incentives, and precedence.
- *Designated projects.* These often occur as commitments for infrastructure such as, roads, utilities, parks, individual buildings, subdivisions, or other developments designated for a specific purpose (e.g., multi-unit housing, shopping mall, hospital, civic centers, parks)

Despite the existence of formal plans and policies to guide land use decisions, in practice, there is enormous variation in how land use decisions are made and what factors are most influential for land use outcomes. Because of this wide variability, it often appears that land use decisions are largely ad hoc endeavors.

Variability in how decisions are made is the norm, yet generalizations are possible. At the state level, local land use authority is governed by enabling statutes (Krane, Rigos, & Hill, 2001). The majority of states follow either Dillon's Rule or Home Rule. Virginia is an example of a state governed by Dillon's Rule, requiring state legislation before local government can implement local land use regulations and fiscal policies. In contrast, states that follow Home Rule can regulate local development and set fiscal policy resides with cities and counties. Variations in the implementation of Home Rule is considerable, moreover, Home Rule practices continue to evolve over time (Barron, 2002-2003).

Additionally, the overall structure of governance varies from state to state. The geographic scope, the presence of overlapping jurisdictions, and extent of inter-governmental coordination are all affected by the structure of local government (International City County Management Association, 2010). In turn, the relative level of jurisdictional fragmentation (i.e., units of local government/person) the relative strength of enforcement responsibility at the county level, the extent to which public utilities and other infrastructure are provided and maintained by the public. All of these factors shape the context for decision-making to build more sustainable communities. Despite the complexity and variability that characterize local land use decisions in the U.S. there are some generally accepted practices attributable to the various levels of governance. These processes are described in the following sections for state, regional, local, neighborhood decision making. Aspects of land use planning that may affect public health are discussed.

State Processes

Over the past 30 years, many states have passed legislation aimed at reining in uncontrolled, haphazard development (see Figures3 and Figure 4) Hawaii is notable for establishing a statewide system of formally designated land use zones. Similarly; a number of other states have adopted significant policies that shape urban development and rural land conservation.

Another motivation for states to update planning statutes is to encourage the preservation of sensitive undeveloped land (Meck, 2002-). Several statewide reforms are specifically designed to improve local land use planning and regulation.

The statewide processes that shape land use and development are primarily about programming infrastructure funds, implementation of state agency policies and project design rather than comprehensive planning.

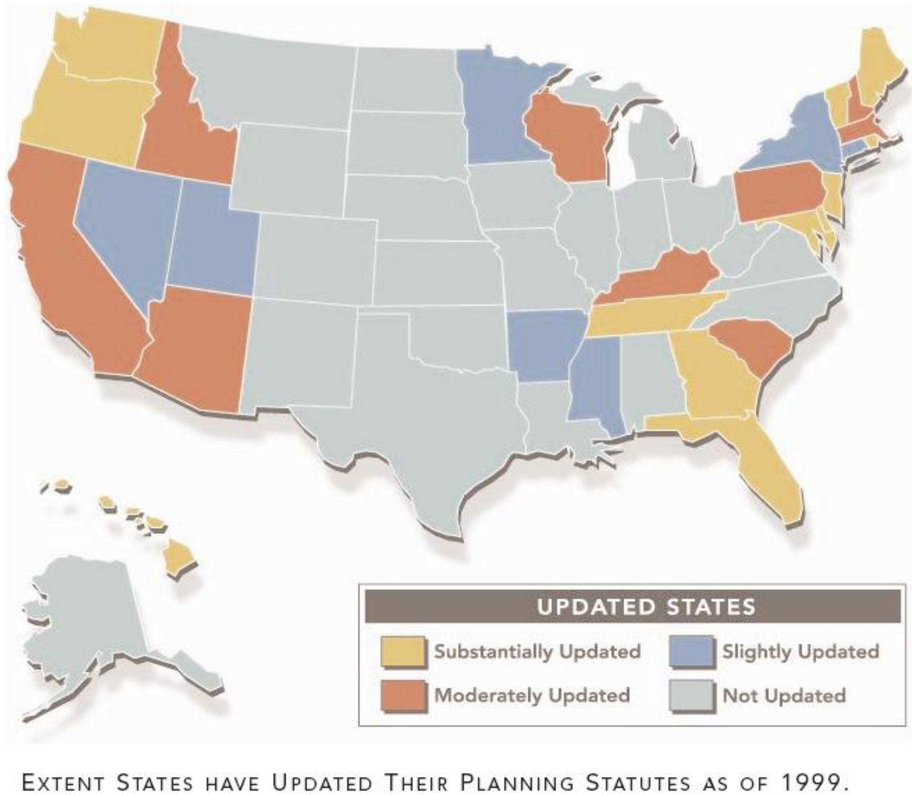


Figure 6 State Planning Statutes (American Planning Association, 1999)

Although State-wide plans do exist, they are focused primarily on policy intended to guide other regional and local efforts to shape development. Two notable exceptions in this category are New Jersey and Maryland. The New Jersey State Development and Redevelopment Plan contains a fairly detailed statewide policy map of land use categories. The Maryland Plan 6) is designed to align state land conservation efforts (e.g., farmland and critical habitat areas), priority growth area designations with state transportation plans.

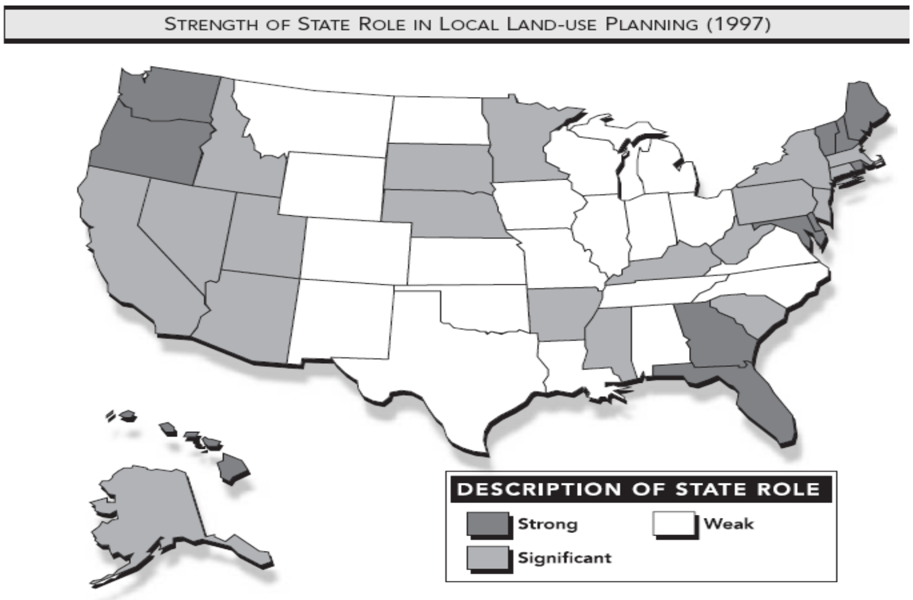


Figure 7 State Role in Local Planning (American Planning Association, 1999)

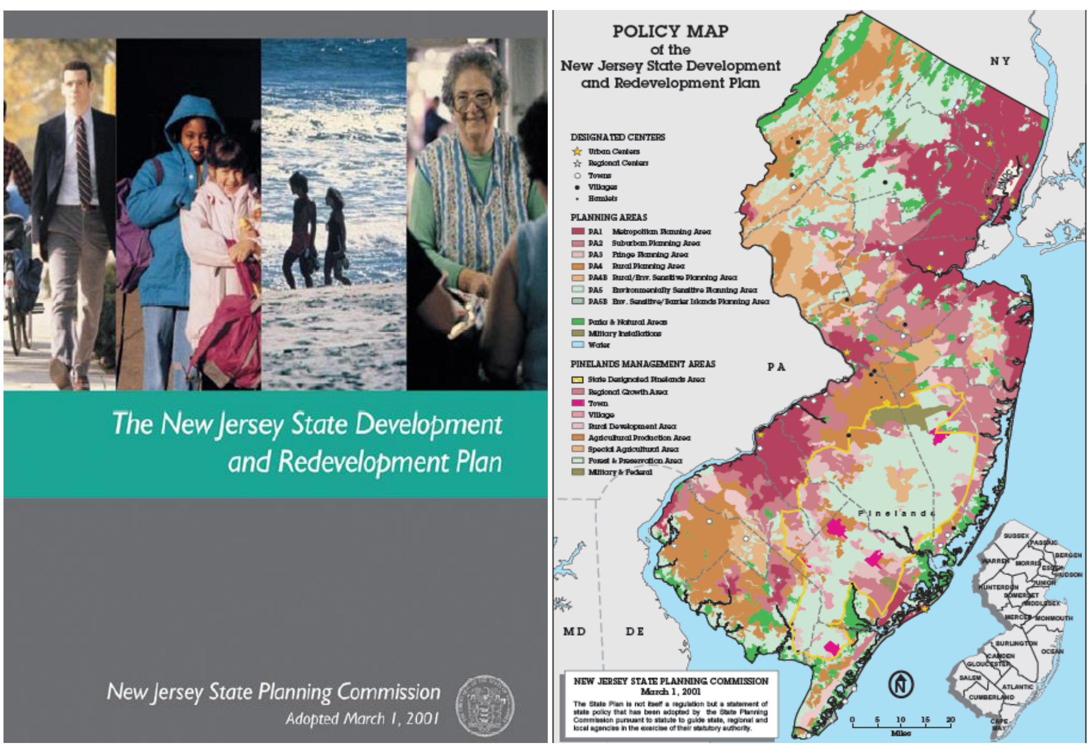


Figure 8 NJ State Development Plan (New Jersey State Planning Commission, 2001)

Figure 9 PlanMaryland (Maryland Department of Planning, 2011)

State agencies also impact land development indirectly through the design and construction of major projects such freeways. For example, the number and design of freeway interchanges, designation of toll roads, and frequency of maintenance can all affect subsequent development and market demand for land.

Regional Agency Processes

At the regional scale, long- range planning and programming for capital infrastructure are the most influential activities that shape regional growth patterns. Across the U.S., 342 metropolitan planning organizations are designated responsibility by U.S. DOT for 20-year, long-range transportation plans and five-year transportation improvement programs (capital plans). Often these regional agencies also govern regional planning for housing and community development. Environmental and economic development is most commonly planned in dedicated organizational units; however, in some cases, the Municipal Planning Organizations (MPO) or Council of Governments (COG) also do regional planning functions related to the environment and economic development.

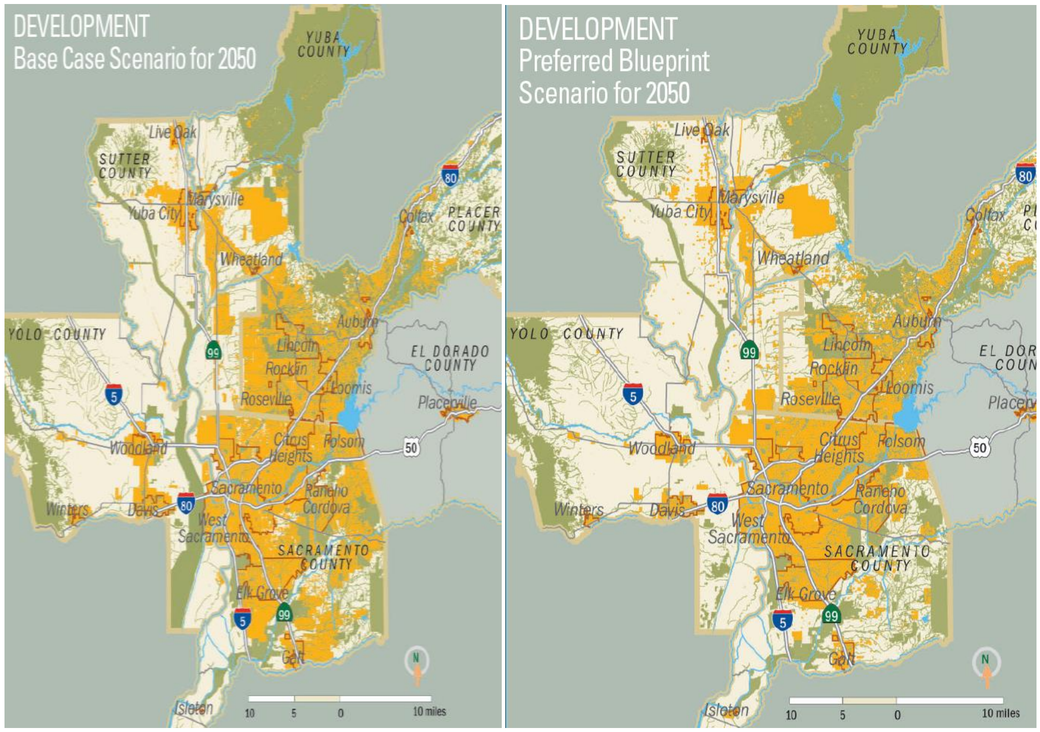


Figure 10 Sacramento Blueprint (Sacramento Area Council of Governments, 2007)

County Processes

The typical role of counties in shaping land use patterns is connected to their approval of development in unincorporated areas and provision of infrastructure (roads, sewer, and water) to serve low density rural development. However, in some parts of the country counties have taken the lead on rural land conservation, particularly farmland protection.

In a handful of states, counties have a larger role to play in the approval of urban and suburban development and the provision of infrastructure to serve such communities. In some cases local government has been consolidated into unified city-county government. In other states (most notably Virginia and Maryland) counties are the primary unit of government overseeing development approval. Finally, in a handful of states, county governments approve significant amounts of development in unincorporated areas just beyond the boundaries of incorporated cities. In each case, the county processes are similar the municipal processes described below. In most instances, county governments do very limited comprehensive planning on land use and development.

Municipal Processes

The municipal governments (cities, towns and townships) are the unit of local government most closely associated with direct control over land use. Some of the basic activities related to land use are defined by state laws and statutes. These statutes create a baseline for the local processes that shape land use in any state, but a number of factors in each city also determine how sustainability is considered – size of the community, level of technical capacity, political culture, etc.

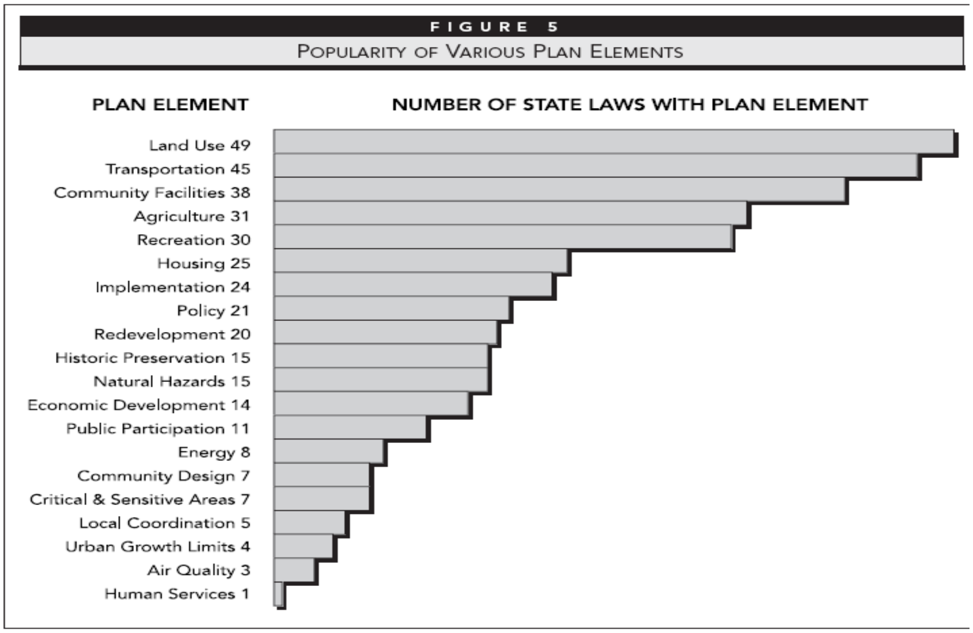


Figure 11 Popularity of Plan Elements (APA, 1999)

Most municipal governments have a general or comprehensive plan in place. With respect to sustainability, many municipalities choose whether and when to do the following: (1) align zoning and other related policies to existing plans, (2) specify a level of detail that facilitates outcomes envisioned in the plan, (3) cover a breadth of functional areas, and(4) update their plans .

Community Priorities

Several recent national surveys elucidate community land use planning priorities, some from the perspective of municipal officials and some from individuals. In 2012, the American Planning Association (APA) polled a statistically valid and representative sample of the U.S. population (a total of 1,308 respondents participated) about their priorities for planning in their communities.

Highest community priorities. A strong majority of respondents (79%) support community planning and 67% believe it is an important element to achieve economic recovery (American Planning Association, 2012). When asked the most important issues for local planners address, job creation (70%) was at the top of the list, closely followed by, safety (69%), schools (67%), protecting neighborhoods (64%), and water quality (62%).

Other community priorities. Often cited as high priorities were bikeways (19%), walking trails (18%), and sprawl (16%). However, when asked to envision high priorities for their ideal community, the most commonly cited elements were having locally owned businesses nearby (55%), being able to stay in the same neighborhood while aging (54%), and the availability of sidewalks (53%), energy-efficient homes (52%), transit (50%), and having neighborhood parks (49%).

Local Policies for Sustainability. The International City/County Management Association, (ICMA), conducted a survey of local government sustainability policies and programs in 2010. They received responses from 2,176 local governments. The economy (94.2%), energy conservation (69.6%), and the environment (60.7%) were most likely to be rated a priority or a high priority, with less than half identifying housing for all income groups (48%), social justice (39%), public transit (34%), green jobs (29%), and climate change (19%) as a priority (International City County Management Association, 2010). In another survey querying planning directors across the nation, the findings indicated that about 30% had incorporated public health goals into their comprehensive or sustainability plans, and that this was often prompted by community support or awareness of public health issues (Hodgson, 2011).

In addition, as mentioned previously, the EPA held listening sessions in 2011 to elicit feedback from stakeholders within and outside of EPA. Communities, trade associations, professional organizations, states, and EPA regions in seven towns and cities across the United States were among those participating in listening sessions. From this diverse group, several frequently mentioned land use and planning priorities emerged. These included: (1) inclusive, well-informed, and collaborative town planning, (2) understanding the unintended consequences or disproportionate burdens of zoning and regulations, (3) increasing higher-density mixed-use infill, (4) preserving open space and agricultural land, (5) increasing access to safe parks and recreational areas, (6) preserving historic places and neighborhoods, (7) adjusting to dramatic increases or decreases in population, (8) reining in sprawl, (9) redeveloping abandoned urban areas, (10) promoting inclusive and aesthetically pleasing design standards (Walters, 2012).

These diverse results illustrate a strong community interest in planning for economic vitality as well as alternative development patterns that emphasize mixed uses and housing types, walkability, and strong community support for local businesses. Neighborhood awareness and interest in meeting needs of aging residents and addressing recreational needs of citizens for accessible parks was evident.

3 LITERATURE REVIEW: IMPACTS OF LAND USE ON ENVIRONMENT, ECONOMY, HUMAN WELL BEING

3.1 IMPACTS OF POPULATION CHANGE ON LAND USE

3.1.1 Urbanization

Urbanization refers to both the rising population in urban centers and the expansion of land developed for human purpose. Increasing populations in urban centers is the combined result the influx of people from rural areas, preferences of immigrants for urban areas, and growth due to births. The portion of Americans living in urban areas, including cities and suburbs, has increased sharply in the past few decades—from about 50% in 1920 to over 80% in 2008 (U.S Census Bureau, 2012). The urban population in the US increases an estimated 1.2% annually (ibid). The portion of land in the United States put to urban use is projected to expand from 3.1% in 2000 to 8.1% in 2050 (D. J. Nowak & Walton, 2005).

Box 6. "Eighty percent of everything ever built in America has been built since the end of World War II. This tragic landscape of highway strips, parking lots, housing tracts, megamall, junked cities, and ravaged countryside is not simply an expression of our economic predicament, but in large part a cause. It is the everyday environment where most Americans live and work, and it represents a gathering calamity whose effects we have hardly begun to measure." James Howard Kunstler. The Geography of Nowhere

Much of the literature on sprawl shows that the amount of developed land per person has increased in the past 25 years (ERS, 2009; U.S Census Bureau, 2012; U.S. Department of Agriculture, 2009).

The decadal patterns suggest that the rate of urban expansion is accelerating (David J. Nowak, Walton, Dwyer, Kaya, & Myeong, 2005). Similarly, deforestation is also increasing to affect ever larger areas (ibid).

Land Development Rate. Reports are conflicting on the rate of land developed per person and whether this rate is increasing or decreasing even as overall populations increase. Holcombe and Staley (2001) challenged reports purporting to show increasing rates of land development per capita; they claimed flawed methodology. In contrast the National Resources Inventory (2007) released methodologically revised figures for land development dating back to 1992. These revised, corrected figures corroborated the finding of the earlier analysis showing accelerated conversion of agricultural and rural land to developed uses (U.S. Department of Agriculture, 2009).

In the 37 most populous U.S. metropolitan areas, urbanized areas have expanded by 57% more than population over the past 20 years (Lewis, Knapp, Schindewolf, & Jamie, 2013). Some have declared this alarming (Kunstler, 1993) (See Box 6)

A movement to curb sprawl and to encourage infill development is having a noticeable impact on urban expansion, particularly in the largest cities. Infill development represents a new land use in a previously developed area. It may involve increasing the intensity of use of a parcel, developing unused land that is surrounded by development, or repurposing previous development to a new use. Among the 51 largest metropolitan areas in the U.S., almost 75% increased the share of infill housing development during 2005-2009 compared to 2000-2004 (US Environmental Protection Agency, 2012b). The percent of new construction that is infill varies widely among cities, from only 2% in Prescott, Arizona, to as high as 80% in San Jose, California (ibid). On average, infill accounts for 20% of all new residential construction for medium and large cities.

Accelerated urbanization can have important impacts on the environment, human well-being, and the economy. One of the challenges for a community is to assure that adverse environmental impacts are managed to minimize loss of ecological goods and services.

Environmental Impacts of Land Development

The development of natural land for human needs is recognized as the primary cause of reduced acreage in wetlands and forest cover. Many of the negative environmental impacts of urbanization have been described in the literature. These negative ecological effects may initially be manifested as increases in peak river flows, in surface water runoff, in stream sediment loads, and in higher concentrations of

Box 7. EPA Product Highlight

EnviroAtlas, SHC Project 1.2.3, is a GIS tool that maps geography, demographics, and the production of ecosystem services. The latter includes immobilization and degradation of toxicants. Shading and cooling resulting from tree foliage. Ecosystems contribute to water quality, carbon sequestration, aquifer recharge, habitat for flora and fauna. Through primary production ecosystems support food and fiber production. Functioning ecosystems can mitigate impacts of natural disasters.

Future releases of the EnviroAtlas will include more types of information, such as built environment measures, transportation, waste, and urban land use. These data can be combined with measured data and models to estimate condition and value of these resources.

The EnviroAtlas is intuitively designed and does not require expertise to navigate its basic functions, therefore it is a resource for a wide variety of users, including local decision makers, natural resource managers, and public health professionals.

nutrients and bacteria (e.g. E. coli).

Impaired Ecological Function: As land is developed for human use, loading of organic and inorganic contaminants to air, water and soil (e.g., nitrogen oxides, mercury, and pesticides) increase (Nagy & Lockaby, 2011). The longer term impacts are likely to be manifested in loss of ecological function, such as decreased carbon storage, loss of species (R. I. McDonald, Kareiva, & Forman, 2008; National Risk Management Research Laboratory, 2010), decreased resistance to perturbations (Bogunovich, 2009; Coaffee, Moore, Fletcher, & Bosher, 2008), whether natural or manmade. Disruptions of energy flow through systems and diminished nutrient cycling may also occur (Nagy & Lockaby, 2011).

Land conversion alters the diversity of local species, and may increase the portion of the regional forest stock within urban boundaries. A projection of urbanization’s effects on ecosystems compared a dispersed scenario at an estimated 50% increase in the per capita consumption of urban land by 2030 compared to a compact scenario that assumed a 50% decrease in the per capita consumption of urban land. The dispersed scenario was predicted to endanger more species worldwide and decreased the buffer around protected areas (R. I. McDonald, et al., 2008).

Urbanization affects flora and fauna and the ecosystems they inhabit. Disruption of species interactions, or habitat disturbance, can cause reductions in native species or outbreaks of invading species to create the emergence of new pest species, such as arthropods, plants, and birds (A. B. Bennett & Gratton, 2012; Decker, et al., 2012; Dolan, et al., 2011).

Only 10-20% of the landscape in city centers is estimated to be capable of supporting plants and animals (A. B. Bennett & Gratton, 2012). Increasing levels of urbanization are associated with declining levels of biodiversity and species abundance. For example, Bennett and Gratton (2012) found that parasitoid diversity decreased by approximately 10% in highly urbanized sites compared to neighboring rural sites.

Urbanization causes deforestation and habitat fragmentation. Approximately 5.3% of forestland is estimated to be subsumed by urban growth by 2050 (D. J. Nowak & Walton, 2005). In most cases, forest is simply cut down; however, approximately 20% of this may remain as urban forest (ibid). All of these changes are cumulative and impact the provision of ecosystem goods and services, which must be balanced with the need for developed land to meet the needs of human society (Hogan et al., 2012; Kramer, 2013).

A projection based in Britain found that the predicted increase in urban land cover by 2031 would have variable impacts on ecosystem services depending on whether growth followed a dense (roughly 20 people per acre) or a suburban pattern (roughly 13 people per acre) (Eigenbrod et al., 2011). The dense pattern increased the proportion of the population living near rivers, increasing impervious surfaces and causing a 10% increase in peak flows due to increases in impervious cover. The suburban pattern tripled the projected loss of stored carbon and agricultural production compared to the densification scenario (ibid). There is evidence that wider riparian corridors dominated by trees may protect stream channels from dramatic changes due to urbanization and densification (Kang, Storm, & Marston, 2010).

Urban Expansion. The expansion of urban areas has particularly important implications for the use and management of public holdings, including national forests, national parks, and state and locally administered resources. As urban residents frequently travel to exurban areas for outdoor recreation, the demands placed on forest ecosystems in close proximity to growing urban centers pose challenges for natural resource managers. Another concern is that of human safety when the public is brought in contact with wild life, such as brown bears, black bears, wolves, foxes, coyotes, and other hazards of the outdoors (e.g. poison ivy, mosquitos, ticks, chiggers, arboviruses).

Heightened resource use, potential conflicts of humans in contact with nature, conflicts regarding recreational opportunities, seasonal and permanent home development can greatly complicate the issues that must be addressed in protecting the health and sustainability of a community expanding its geographic perimeter into natural areas. Because of these potential conflict, urbanization has been predict by some experts as one of the most significant impacts of land use in 21st century (David J. Nowak, et al., 2005).

Box 8. "Land-use policies can affect trends, but only so much. The basic economic and demographic factors shaping land-use changes in the United States are powerful, and even fairly dramatic policy changes, showed only moderate deviations from the business-as-usual scenario. . . . Land-use policies can affect trends, but only so much. The basic economic and demographic factors shaping land-use changes in the United States are powerful, and even fairly dramatic policy changes, showed only moderate deviations from the business-as-usual scenario." *Radeloff, 2012*

Economic benefits of agglomeration

Studies on the economic and human well-being impacts of urbanization are becoming more prevalent. Some authors contend that urbanized areas benefit from agglomeration, which produces greater innovation, efficiencies and productivity (Seto, Sanchez-Rodriquez, & Fragkias, 2010).

As more of the country becomes urbanized and a larger portion of the population lives in cities, these societal benefits may accrue. Increases in social interaction and information networks associated with more dense living conditions could stimulate increases in both innovation and productivity for city dwellers. An alternative perspective has been presented by Radeloff (2012) in which he points to the limitations of land-use policies in shaping land use in the U.S. (see Box 8).

Environmental awareness and urbanization

Based on a survey, Nagy and Lockaby (2011) reported that environmental awareness declines as populations became more urbanized. Environmental awareness, such as recognition that forests contribute to water quality, was highest among groups involved in outdoor recreation or employment, which is uncommon among city dwellers. This finding suggests that increased outreach and opportunities for outdoor recreation promote environmental awareness among urban residents and may be important for fostering concepts of environmental stewardship in future generations.

Gentrification

Urbanization tendencies can be detrimental to wellbeing of lower SES groups. The reinvestment in city centers that follows population growth has been implicated for spurring gentrification in some cities and shrinking towns elsewhere. Gentrification is the transformation of urban neighborhoods towards higher incomes, more expensive housing costs, and predominance of advanced education levels, and is considered a fundamental process which accelerated in the 1990s (Abel & White, 2011). The consequence of all this upward mobility is the marginalization of lower income people. Those who service the community are excluded from it. Lower income residents may be displaced, particularly if provisions for affordable housing are inadequate. For example, increasing demand for walkable urban neighborhoods has led to gentrification in historically affordable neighborhoods in the city centers, displacing poorer residents in some cases. The Brookings Institution found “places with more walkable features have…become more gentrified over the past decade” (Leinberger & Alfonzo, 2012).

While revitalization of city centers is generally framed as a positive change, lower income residents may be displaced to less safe or undesirable areas, exacerbating inequities. A study in Seattle indicated that gentrifying areas were less likely to contain facilities that filed for toxic release inventories (TRI). Of the 11 new faculties reporting to TRI during the one year study period, none of them were in gentrifying areas (Abel & White, 2011). In a study of hypertension prevalence in Chicago, the researchers looked at health impacts of proximity to TRI facilities. Hypertension was found to be less common in gentrifying neighborhoods, even after controlling for other known risk factors (Morenoff et al., 2007).

Thus, urbanization is tied to numerous economic, societal, and environmental consequences that can create concerns for disproportionate exposures. The pressures in play to create gentrified neighborhoods can also foster and exacerbate homelessness, segregation, and destroy neighborhood cohesiveness for some factions of society.

Quantitative relations for urbanization

Throughout this report, sections on “Quantitative relations” are used to highlight correlations between land use qualities and outcomes that have been quantified. These are *not necessarily the most important associations, nor does inclusion signify statistically significant results. Rather these are the instances we encountered for which quantitative parameters were presented. All of the quantitative sections are delineated by green backgrounds for easy navigation.*

- A 50% increase in per capita consumption of urban land worldwide would put 3% of species at-risk of extinction by 2030 (R. I. McDonald, et al., 2008) Another approximation is that of Thomas et al., 2004, who estimated an 18% extinction rate estimated to be caused by global climate change (Thomas et al., 2004).
- Seventy-one percent of large metropolitan regions saw an increased share of infill housing development (US Environmental Protection Agency, 2012b).
- A suburban growth pattern has been projected to cause three times more loss of stored carbon and agricultural production compared to a densification scenario in Britain (Eigenbrod, et al., 2011)
- A dense growth pattern has been projected to cause a 10% increase in peak river flows by 2031 (Eigenbrod et al, 2011)

3.1.2 Sprawl

Emergence of sprawl

Sprawl was recognized as an emerging landscape attribute in 1937 by Earle Draper (Black, 1996). He coined the term "sprawl" to describe an unintended consequence of converging economic and social drivers to have an unplanned negative impact on the environment. The environmental impact is that of reduced natural capital and ecological services.

With the end of World War II, returning veterans became a significant demographic group with the energy, appetites, and growing affluence to drive markets for manufactured goods and land. Federal programs and policies including the GI Bill, the 30-year mortgage, the Federal Highway Act, the affordability of the automobiles, and a zoning process that separated uses and often required minimum lot sizes culminated in the greatest economic expansion the United States ever experienced.

The result was a life style where people from the most humble beginnings could expect that hard work combined with modest investments to learn vocational skills, apprenticeships, and professional skills could enjoy the rewards of full employment, material wealth, health care, leisure time, and well educated children, and other amenities characterized as "the good life".

Thus the population of the country improved its life style and life expectancy to achieve privileges reserved for the wealthy in previous eras. This realization of the American dream materialized as proliferation in single family houses, with big yards, with space for gardens and play areas for children.

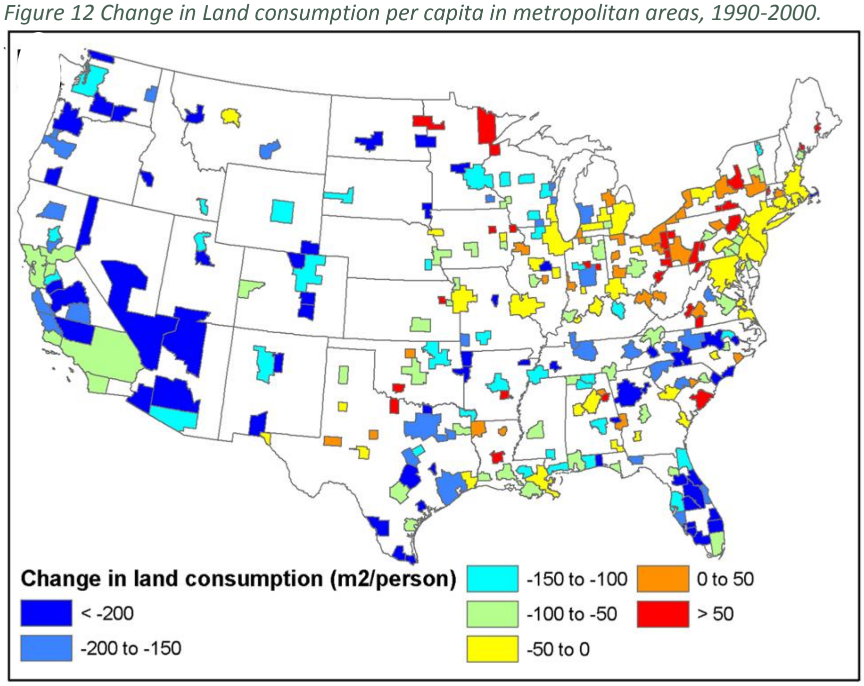
Although sprawl was spawned during a period of exuberant economic expansion and population explosion, this land-intensive form of expansion is still the predominant form of growth in major metropolitan areas (R. W. Burchell & Mukherji, 2003). In recent decades, both inexpensive gasoline prices and the introduction of telecommuting options may have further enabled sprawl. Lower fuel prices keep travel affordable; telecommuting makes travel to work unnecessary.

Sprawl today

Nearly all metropolitan regions are growing outward more than they are growing upward (multistory buildings) or inward (land reuse or urban redevelopment) (Box 9). From 2005 to 2009, more than 200 metropolitan regions still had the majority of new home construction in undeveloped green fields. Urban infill is not a common approach to satisfy the market demand for land by urban populations (US Environmental Protection Agency, 2012b).

The rate of outward expansion from the urban core may have slowed in recent years; however, sprawl and decentralized growth are still predominant growth patterns throughout the United States (Kramer, 2013; US Environmental Protection Agency, 2012b). Per capita utilization of land, that is the area of land occupied per person, continues to increase although the rate of increase may have slowed over the past 25 years (R. I. McDonald, Forman, & Kareiva, 2010). Regional variations exist, for example, in Maryland single family lot sizes increased in the 1990s (Kopits, et al., 2012) consistent with increases in per capita utilization of land despite population declines (Hasse & Lathrop, 2003). A study by the Urban Transportation Center showed that in the Chicago area, decentralization peaked in the 1960s and declined through the 1990s (Sen et al., 1998).

Figure 12 Change in Land consumption per capita in metropolitan areas, 1990-2000.



More recent literature acknowledges that sprawl manifests in multiple ways (Carruthers & Vias, 2005; Kumar, Pathan, & Bhanderi, 2007; E. H. Wilson, Hurd, Civco, Prisloe, & Arnold, 2003; Zhang & Wang, 2006; G. Zhou & He, 2007). In addition to a continuous low density expansion outwards associated with suburban development, exurban, monocentric, polycentric and leapfrog patterns of expansion have emerged. The expression exurban, from extra-urban, generally refers to a primarily residential commuter towns (aka "bedroom communities") on the outskirts of a town or city (Suarez-Rubio, Lookingbill, & Wainger, 2012). These are situated beyond suburban areas, and are often characterized as leapfrog developments that are separated from the city by rural or open space.

Developed land per capita was higher on average in 2007 than it was 25 years ago. This fact, combined with an increasing population, establishes good reason to conclude that the current rate of land utilization is unsustainable. In this case, unsustainable is a function of the calculation that the there is not enough land on earth to satisfy continued rates of land occupancy per capita.

Over the past 25 years, there has been over a 55% increase in the amount of land developed nationally (70.96 million acres in 1982 compared to 111.25 million acres in 2007) (ERS, 2009). This 55% increase in developed land was accompanied by a 30 percent increase in the US population (238 million in 1982 compared to 308 million people in 2007) (U.S Census Bureau, 2012). From a national perspective, this is an increase in land consumption from 0.29 acres per person in 1982 to 0.36 acres per person in 2007.

Box 9. EPA Product Highlight

The EPA Office of Sustainable Communities produces a semiannual report on residential construction trends. The most recent, in 2012, compared the location of new home construction to the pre-existing land cover to determine the extent of infill development in 209 U.S. metropolitan regions between 2000 and 2009. The report paints a detailed picture of the national trend towards infill, highlighting the metropolitan areas where infill is most and least common.

Land conversion in the United States is expected to increase the percent of developed urban land from 3.1% to 8.1% by 2050, consuming a significant amount of forest and cropland (D. J. Nowak & Walton, 2005). In 2003, Burchell and Mukherji, 2003, estimated that 18.8 million acres of land would be used to build 26.5 million new housing units as well as 26.5 billion square feet of new nonresidential space (R. W. Burchell & Mukherji, 2003).

Transportation enables sprawl

Sprawl has been perpetuated by the increasing availability of private transportation (French, Story, & Jeffery, 2001; Frumkin, 2002) and the trend to geographically separate different land use types. The availability of land to be developed is also a key ingredient for sprawl. Several authors have reported that the number of vehicle miles traveled per day per person increases as the housing density of an area decreases; that is housing density is inversely proportional to vehicle miles traveled by residents of that community(Frumkin, 2003; United States Environmental Protection Agency, 2001). Travel requirements inherent in different forms of development can significantly impact ecological health as well as human health. Specialized land uses, such as residential, commercial, agricultural, industrial, have created a dependence on automobiles just to meet basic needs for employment, schooling, shopping, and social interactions. The automobile and national highway system, combined with the post World War II population growth, have accelerated the rate of sprawl and the emergence of a host of environmental, economic, and social and health.

Negative aspects of sprawl

Sprawl has been reported to accompany almost every unwanted or unattractive aspect of U.S. urban life. The long list of negatives attributed to sprawl include the following:

air pollution	inner-city abandonment
an increase in extreme heat events	loss of biological diversity
crime	loss of farmland
decreased pedestrian safety	loss of social capital
destruction of built environment,	obesity
destruction of communities	overdependence on cars
destruction of open space	overreliance on septic systems
excess energy use	poor health
high taxes	racial segregation
homelessness	street gangs
income inequality	urban pests
increased public infrastructure	urban blight
increased service costs	vermin
increased traffic fatalities	water pollution

Compiled from: (Baron, et al., 2009; Bullard, 2000; R. Burchell et al., 1998; Duany, et al., 2000; R. Ewing, Schieber, & Zegeer, 2003; Heimlich & Anderson, 2001; Irwin & Bockstael, 2004; Jackson, 1985; James et al., 2013; Kunstler, 1993; Russ Lopez & Hynes, 2003; National Research Council, 2009; Northridge & Freeman, 2011; Popenoe, 1979; Speir & Stephenson, 2002; Stone, Hess, & Frumkin, 2010; Tu, Xia, Clarke, & Frei, 2007).

Social Capital and Urban Sprawl

In the context of sprawl and urban communities, social capital refers to diverse measures of social contact and networking, including frequency of social contact, civic participation, measures of trust and cooperation, voting, patronage of local businesses.

When viewing trends in urban land use from a systems perspective, “suburbia” emerged as a new landscape pattern co-incident with a major demographic shift of the more affluent, professional workers and their families away from urban neighborhoods. Remaining properties lost value as homeowners were replaced by renters. A downward sociological spiral took hold that caused many cities to spawn a phenomenon of inner city decay that became known, at its worst, as “urban blight.” As the demographics of metropolitan areas shifted to favor those of lesser SES means, the incidence of violence and crime often increased. New academic disciplines were established (e.g. urban ecology, city and regional planning, criminology, urban metabolism) to understand the dynamic interplay of social, economic, and environmental parameters that characterized a growing proportion of the human landscape.

Negative Ecological Impacts of sprawling urban land forms have been shown to occur by numerous mechanisms. Sprawl has been positively associated with (1) accelerated rates of land conversion from natural to built environments (Heimlich & Anderson, 2001), (2) habitat fragmentation (Tscharntke et al., 2012; Wang & Moskovits, 2001) and (3) Disruption of ecological functions such as primary production, nutrient cycling (Blann, Anderson, Sands, & Vondracek, 2009), energy flow, decomposition, critical habitat loss for plant and animal species (Hasse & Lathrop, 2003).

Land cover changes associated with sprawl

Loss of natural land to the built environment can have profound impacts on natural resource reserves. Worldwide, urban expansion is one of the primary drivers of habitat loss and acceleration of extinction rates of native plant and animal species (R. I. McDonald, et al., 2008). Loss of forested land alone may jeopardize the supply of forest products and associated ecosystem services (Nowak and Walton 2005). A sprawling land use pattern has been linked to greater loss of carbon storage both above and belowground and a decrease in net primary productivity (A. Schneider, Logan, & Kucharik, 2012).

Apart from the loss and fragmentation of natural landscapes, the alterations associated with a sprawling urban form include more impervious surface cover, many irrigated and fertilized yards, increased use of septic systems and contamination of subsurface aquifers. The loss of regional forest reserves and the increase in non-reflective surfaces such as roads and rooftops contribute to extreme heat events (Stone, et al., 2010). Expansion of turf grass acreage in residential areas alone is associated with a reduced capacity to adapt to flooding (A. Schneider, et al., 2012) and a reduction in the time required for aquifer recharge. Water quality in watersheds has been shown to decrease over time as sprawl progresses. Tu and colleagues (2007) showed that the impact of urban sprawl on water quality

Box 10. Envision Integrated Modeling Platform is a GIS-based framework to create alternative future scenario applications. The tool consists of a dynamic spatial engine and an open extensible architecture that allows any number of process models, evaluative models, visualizers, and analysis modules. Together, the framework allows simulation of land use change and documentation of resulting effects on indices of ecosystem, social, and economic services.

http://envision.bioe.orst.edu/

comes from the combined effect of population growth and land development.

Infrastructure changes associated with sprawl

Land use policies that allow or encourage extensive development beyond the extent of water and sewer infrastructure increase the number of households that must rely on well water and septic systems. Residences within municipal boundaries are typically served by centralized water treatment and centralized sewage treatment. When residential development surpasses municipal boundaries, development tends to proceed unabated into areas without centralized treatment facilities.

Increased use of septic systems raises the risk of sewage backflow and seepage into water delivery systems, increasing the opportunity for long-standing contamination of drinking water supplies to go undetected (US Environmental Protection Agency, 2012c). The failure rate of septic systems has been estimated to range from 5 to 30% (T. Schueler, 2000) and can increase with age of the system.

Impact of sprawl on agriculture and food security

The increased rate of land conversion from agricultural usage to other purposes poses a realistic threat to food security. With a growing urban population and the trend for suburban development, which is often at the expense of fertile cropland the proportion of land surface devoted to agriculture continues to decline (e.g. from 63 percent in 1949 to 51 percent in 2007(ERS, 2011a). Current rates of increase in agricultural productivity will not compensate for this land loss (Ayres & McCalla, 1996; Francis, et al., 2012).

Gradual declines have occurred in cropland, pasture, and range; grazed forestland has decreased more rapidly. The conversion of rural land to developed uses tends to be irreversible and can reduce resilience of systems to perturbations (Sidle, et al., 2013). Over the past several decades, over half of the land that converted to developed uses was previously in an agricultural use (ERS, 2011a). Urban and rural residential land acreage quadrupled from 1945 to 2007, increasing at about twice the rate of population growth over this period. Land in urban areas was estimated at 61 million acres in 2007, up almost 2 percent since 2002 and 17 percent since 1990 (ERS, 2011a).

Based on data from the National Resources Inventory (NRI) from the 1980s, 46% of land converted to urban uses came from cropland and pasture (Heimlich & Anderson, 2001). In the United States, 500,000 hectares are converted away from food and fiber production each year. It is estimated that, assuming a 1% annual population growth, the land per capita devoted to food production will be cut in half by 2050, from 0.6 ha per person to 0.3 hectares (Francis, et al., 2012). In North Carolina, between 1997 and 2011, about 15% of the state's cropland was lost and employment in the agriculture industry dropped by over 7% (The Trust for Public Land, 2011). Research has shown a link between sprawl and reduced agricultural production (Eigenbrod, et al., 2011; Francis, et al., 2012).

Agricultural land fell by 45.9 million acres from 1992 to 1997, whereas developed land only increased by 29.9 million acres during the same period (Holcombe & Staley, 2001). These numbers suggest that development is unlikely to have been the primary cause of cropland loss. Moreover, urbanization only accounted for 26 percent of farmland loss between 1945 and 1992 (Tweeten, 1998). The majority of land conversion was to recreation, rangeland, forest, or parkland.

Conversion of farmland to urban use is likely to be prime farmland (Hasse & Lathrop, 2003; Imhoff et al., 1997; Munroe & York, 2003). This is at least partly because the characteristics of land that are essential for growing high value produce—warm temperatures in winter, good supply of water, level land, and well drained soils— are also valued for urban development (Heimlich & Anderson, 2001). Furthermore, farmland loss rates are uneven; some states and counties have very elevated rates of farmland loss. Urbanization may not be the largest contributor to farmland loss nationally; nonetheless, high conversion rates may impact local agriculture. Preservation of farmland for future use may help to assure for food security in the future (Tweeten, 1998).

Box 11. EPA Product Highlight

The Integrated Climate and Land-Use Scenarios (ICLUS), ACE Task 137 (U.S. Environmental Protection Agency, 2009). The ICLUS is an online mapping tool developed that maps US population and housing density scenarios through 2100 to create estimates of the impacts of climate and land use change scenarios. Scenarios and underlying data will be useful for regional planners, local governments, state agencies, non-profit organizations, and universities interested in long-range local, statewide, regional or national analyses.

Urban sprawl is also regarded as a detractor from scenic beauty, habitat integrity, and continuity of home ranges for fauna and flora (G. S. Anderson & Danielson, 1997; Beier & Noss, 1998; Ignatieva, Stewart, & Meurk, 2011)

Communities seeking to preserve agricultural land, whether for economic livelihoods, food security, or to maintain a rural aesthetic, several options are available to manage land use. These include zoning policies, conservation measures, transfer of development rights, and use of compact development forms.

Agricultural conservation reserve zones have been used to preserve dwindling agricultural land from development. Also, zoning can protect agricultural lands to some extent; however, studies show that the most significant predictor for the conversion of agricultural land to urban land is the combination of the land rent, land characteristics of slope, productivity, etc., and population of the area (York & Munroe, 2010). In general, zoning for the express purpose of limiting urban expansion or to offset the loss of agricultural lands has proven to be ineffective below the county level (York & Munroe, 2010).

Coordinated action at the regional level, theoretically, should be effective. Scenario models to predict land use changes have shown that agricultural production is reduced under sprawl and "business as usual" scenarios when compared to compact development scenarios. For example, a model based in Britain showed that loss of agricultural production was three times as high under a sprawl scenario as under a densification scenario (Eigenbrod, et al., 2011).

Box 12. EPA Product Highlight:

The Report on the Environment, SHC Task 3.4.2, is released every 4 years to describe recent trends in land use and land cover and to track changes in several land use and land condition indicators including land cover of various types, ecological condition of undeveloped land and developed land relative to population change.

It is a valuable resource for researchers, land use planners, natural resource managers and policy makers as a resource for recent national trends in land use, land cover, and ecological functioning.

The list of indicators used to track these trends may be useful to modelers and sustainability index developers looking for standard metrics with documented data sources.

Unintended consequences of policies to preserve agricultural land could be disproportionate adverse effects on minorities and low-socioeconomic groups. Higher rates of preserved agricultural land have been associated with high incomes and high property values (Poor & Brule, 2007). This creates a conundrum of which came first. The trend implies that when agricultural conservation policies are implemented, low socio-economic residents are displaced. An alternative explanation is that residents of higher income areas value conservation more highly that lower SES population.

If the results are merely descriptive of the existing demographic, then preservation of agricultural land in lower income communities may be a cost-effective way to maintain food security before an area becomes gentrified (Warren, Ryan, Lerman, & Tooke, 2011).

Not considered in this review is the interplay between loss of agricultural land versus improved agricultural productivity on poor quality land or the influence of international markets on food supply in this country. If external food resources become less costly and of equal quality, domestic markets will move to international sources. This dynamic is also likely to prevail if landowners receive more for their land when sold for development than can be received for agricultural productivity.

Physical fitness, transportation and sprawl

Impacts of sprawl on both human health and ecological services are documented for a variety of endpoints. These endpoints include physical and mental health, safety, exposure to environmental pollution, and consequences for social capital. Social capital includes such intangibles as aesthetics, spirituality, social networks, and neighborhood identity. Residents of communities characterized by high population density, mixed land use, and by spatial connectivity to other communities, report greater reliance on walking and cycling to get around when compared to residents living in low-density, isolated neighborhoods devoted to single purpose land use (Saelens, Sallis, & Frank, 2003).

Obesity and Sprawl. Obesity in the United States is at a historic high, to the extent that it's been described as an epidemic. A link between obesity and urban sprawl is well documented in the literature. Physical inactivity is positively correlated with sprawling urban form; obesity is also positively correlated with lack of walkable urban space.

Sprawling urban form fosters high reliance on driving but not on walking to get around (Frumkin, 2003; United States Environmental Protection Agency, 2001). Studies have also shown a greater incidence of hypertension (R. Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003), higher body weight or BMI (Reid Ewing, et al., 2003; James, et al., 2013; James et al., 2009; Joshu, Boehmer, Brownson, & Ewing, 2008; R. Lopez, 2004; Seliske, Pickett, & Janssen, 2012; Slater et al., 2010; Z. Zhao & Kaestner, 2010) in suburban communities than was evident in reference groups. Numerous community studies have confirmed that communities designed to promote physical activity are successful in doing so (Sivam, Karuppannan, Koohsari, & Sivam, 2012) and thus can promote a healthier life style. Not all studies are so straightforward, Griffin et al. (2013) showed a higher probability of coronary heart disease or myocardial infarction in women associated with greater physical activity.

Compact urban form has been associated with less sports participation among youths (Slater, et al., 2010). A lack of statistical rigor and the presence of multiple confounding factors have yielded equivocal results for many studies in the literature (Doyle, Kelly-Schwartz, Schlossberg, & Stockard, 2006). One such confounding factor is the perception of safety, which is a very strong predictor of walking. Attempts to control for safety did not resolve associations between walkability and weight (Doyle, et al., 2006). Other neighborhood characteristics such as traffic, unleashed dogs and personal limitations such as injury and lack of free time can obfuscate results (Joshu, et al., 2008).

Rural Sprawl. Sprawl is not restricted to urban development; rural communities can also display both sprawling and compact development forms. Rural residents can just as easily be affected by the negative health impacts of an automobile-dependent development patterns.

Among rural populations showing elevated incidence of obesity, patterns of land use development and automobile use were again implicated as contributing factors (Dalbey, 2008). Compact, walkable, mixed-use, rural communities have been recommended to support and encourage active life styles. Reliance on the automobile for multiple daily trips, including commuting, transport to schools, shops, civic and cultural amenities, and recreation was seen as contributing to unhealthy lifestyles that can be remedied in part by compact community design.

Air quality, water quality, and sprawl

This reliance on the automobile has resulted in another category of health concerns. Automobile use results in the creation of a variety of air pollutants, both gases and particulates, that vary from region to region, season of the year, time of day, as well as with the properties of fuel used.

Another potential health impact from sprawl is the increased use of septic tanks and wells. Improperly treated sewage can pollute waterways, beaches, and recreational waters. Sewage concentrations in recreational waters have been found to increase the risk of swimming associated gastrointestinal illness, especially in children under 10 years of age (Wade et al., 2008).

Well water can be a danger to rural households if there is groundwater contamination in the area, which is common particularly during wet weather conditions. Schueler (2000) concluded that even minimal development in a watershed leads to almost inevitable violation of bacterial water quality standards during 37 very wet as well as during very dry weather. The author highlighted studies showing 30-60% of shallow wells in Maryland had detectable levels of fecal coliform, fecal contamination was more likely on properties with septic systems (ibid). Bacterial contamination comes from a variety of sources including farmland, failing septic systems, sewer overflows, and illicit connections to storm sewers, as well as nonhuman bacterial sources (birds, domestic animals, and pets).

Environmental justice and sprawl

Certain land use regulations associated with a sprawling development pattern may disproportionately impact on the poor populations. Zoning codes that require large minimum residential lot sizes are commonly referred to as exclusionary zoning. This appellation reflects the effectiveness of ordinances in pricing out lower income residents. In this way, sprawl has the capacity to exacerbate economic segregation, which is discussed further under the section on residential land use.

Infrastructure costs and sprawl

A dispersed development pattern impacts water and sewer costs. Water and sewer infrastructure costs for compact, contiguous development patterns are only 60-66% what they are for more dispersed patterns (Speir & Stephenson, 2002). Larger lot sizes, more disperse lots, and longer distances all increase water and sewer service and infrastructure costs independently and cumulatively, though they are most sensitive to lot sizes. Doubling lot sizes increases water and sewer costs by 30% on average (Speir & Stephenson, 2002). Subsequently, residents in more compact areas of a municipality may be subsidizing the infrastructure and service costs of those in more suburban areas, through both taxes for the initial infrastructure investment, and then through utility fees, which are often averaged over an entire region (Speir & Stephenson, 2002).

Affordability and sprawl

Sprawling residential areas are generally associated with lower housing costs and higher transportation costs than compact areas. Although housing tends to be more expensive in compact areas (Burton, 2000), the total costs of housing and transportation must be considered to gain a true picture of affordability. There is a tradeoff between these costs and whether one cost offsets the other varies by region and circumstance. On average however, research has shown that for every dollar a household saves on housing, it spends $0.77 more on transportation (Roberto, 2008). This only hold true up to a certain threshold however; transportation costs usually outweigh the housing savings for a commute longer than 12–15 miles (ibid).

Furthermore, sprawl separates people from employment centers. For the poor, employment may be hard to reach because of inability to find or afford essential transportation to jobs (Center for Neighborhood, 2012; Roberto, 2008). For more discussion of housing and transportation affordability, see the Regional accessibility and Regional density sections of this paper.

Quantitative relations for sprawl

- Doubling lot sizes increases water and sewer costs by 30% on average (Speir & Stephenson, 2002).
- In small communities in America, over 60% of households rely on septic systems for waste disposal (US Environmental Protection Agency, 2012c).

- Expansion of turf grass acreage in residential areas alone is associated with a reduced capacity to adapt to flooding (projected increases in U.S. Corn Belt will lead to between 15-48% increase in runoff) (A. Schneider, et al., 2012)
- Losses of agricultural production are over three times as high in sprawl scenarios compared to densification scenarios in growth projections (Eigenbrod et al. 2011, Francis et al. 2012).
- 60% of development on farmland took place on prime farmland in New Jersey (while only 53% of farmland is 'prime') (Hasse and Lathrop, 2003).

3.1.3 Shrinking towns and cities

What is considered a rural community? There are many ways to describe rural communities based on their economic, geographic, or design characteristics. Certainly, each community is unique, and rural communities can include a number of complex and contradictory qualities. However, characterizing them can help identify common challenges they may be facing as well as opportunities that may help them adopt a sustainable approach to growth and development in the future. Most rural communities can be grouped into five categories, though many may fall into more than one: (1) Gateway communities, (2) Resource-dependent communities, (3) Edge communities, (4) Traditional Main Street, and (5) Second home and retirement communities (International City/County Management Association, 2010). Alternately, communities can also be characterized quantitatively by their population. Small population size typically characterizes a rural place with population thresholds used to differentiate rural and urban communities ranging from 2,500 up to 50,000 people. Researchers and others who analyze conditions in "rural" America most often use data on nonmetropolitan (nonmetro) areas, defined by the Office of Management and Budget (OMB), on the basis of counties where population and economic trends can be tracked.

Recent studies have shown that the face of declining cities and regions is no longer primarily limited to older manufacturing towns, urban cores, and declining rural farming communities. As a result of economic downturns, in particular housing foreclosures across the nation, suburban areas experienced the greatest decline (42.8%) in housing occupancy during the period of 2006-2009 of economic downturn than the previous 2000-2006 housing boom period as compared to rural (13.8%) followed by urban areas with the smallest decrease (1.9%) (J. Hollander, Polsky, Zinderr, & Runfola, 2011). Regionally, the Sunbelt area (Phoenix, Las Vegas, Los Angeles, San Francisco Bay, New Orleans and the outskirts of Florida's coastal cities) showed noticeable increases in declining housing, where massive new housing developments are largely unoccupied while older housing is abandoned due to foreclosure akin to those observed in former industrial Rustbelt cities. In addition, the upper Midwestern states (Michigan, Wisconsin, Northern Illinois and Minnesota) exhibited a similar decline. In contrast, the Great Plains, Mississippi River corridor, western Pennsylvania, and Pacific Northwest was either less pronounced or reversed (J. Hollander, et al., 2011).

Rural population loss

Population loss is a longstanding concern among rural development practitioners, and one that goes hand in hand with urbanization. Nearly half of today's nonmetropolitan counties lost population through net out migration over the past 20 years; for over 700 counties (over a third of non-metro counties), this loss has exceeded 10 percent (ERS, 2011b). In July 2011, non-metro America had just over 51 million residents, over the last decade, a 4.5-percent increase in the non-metro population, less than half the metro rate. However, populations declined in most rural and isolated counties within the non-metro areas, while rising moderately in more urban counties. In fact, many of the fast-growing non-metro towns have been reclassified as metro or became part of existing metro areas through suburban expansion. Today, non-metro areas contain 16 percent of the U.S. population distributed across 75 percent of the land area, compared with 21 percent of the population (and over 80 percent of the land area) in 1990 (ibid).

Local economic impacts in shrinking towns

Population loss tends to increase tax burdens, reduce property values, and reduce both the demand for and supply of local goods and services. Rural outmigration is also troublesome because it is highly concentrated among young adults, especially those possessing or acquiring education and skills. In general, young adults leave rural areas to attend college, serve in the military, or see the world. Rural areas gain population through the in-migration of young families, midlife career changers, and retirees.

Some of these counties have had very high poverty rates, substantial loss in manufacturing jobs, and high unemployment. Lack of economic opportunity was likely a major factor in their high outmigration. Most high net outmigration counties, however, are relatively prosperous, with low unemployment rates, low high school dropout rates, and average household incomes. For these counties, low population density and less appealing landscapes distinguish them from other non-metro counties. Both types of outmigration counties stand out on two measures, indicating that quality-of-life factors inhibit in-migration: a lack of retirees moving in and local manufacturers citing the area’s unattractiveness as a problem in recruiting managers and professionals (ERS, 2010).

Which areas are most vulnerable?

Rural businesses and industries often specialize in resource based activities such as agriculture, forestry, mining, or natural amenity-based recreation. In addition, manufacturing establishments--some involved in processing food, wood and mining products, but most in activities unrelated to local natural resources--have been a key part of many rural economies. Furthermore, U.S. rural areas have been disproportionately affected by the loss of textile and apparel jobs, particularly in the Southeast, where textile and apparel plants were concentrated (ERS, 2006).

Rural (non-metro) industry employment earnings underwent major changes between 2001 and 2010. Although farming, forestry, and fishing inflation-adjusted earnings were together nearly 14 percent higher in 2010 than in 2001, this disguises estimated declines of about 30 percent in both forestry and fishing, hidden by a 22 percent gain in farm earnings. Mining, which had been shedding jobs and earnings in recent decades, experienced a substantial increase in earnings (45%), due largely to growth of natural gas extraction from unconventional sources, particularly from shale. In addition, earnings grew substantially in health and educational services and government over this period (35% all rural earnings in 2010) (ERS, 2011b).

Future population shifts

The future could see additional migratory shifts. Members of the baby boom cohort, now in the mid-forties to mid-sixties, are approaching a period in their lives when moves to rural and small-town destinations increase. Non-metropolitan counties are likely to experience the greatest surge in baby boom migration during 2000-20. People reaching their fifties and sixties have a significant propensity to migrate to non-metro counties with more isolated settings, especially those with high natural and urban amenities and lower housing costs. If baby boomers follow past migration patterns, the non-metro population age 55-75 will increase by 30 percent between now and 2020 (ERS, 2009).

Best Practices and Unintended Consequences

Communities with declining populations or a contracting economy face a combination of problems: unemployment and poverty, increasing demands for social services with fewer dollars to pay for them, an aging workforce, vacant properties, and loss of historic structures. Attempts to compete with other jurisdictions for large economic development projects, such as new manufacturing plants, office parks, or regional big box retailers, may come at the expense of local businesses and the communities they aim to support (International City/County Management Association, 2010).

Although shrinking towns and cities do not necessarily have lower neighborhood quality (J. B. Hollander, 2011), significant population loss does lead to more vacant properties, which is a challenge for community planners. The literature emphasizes several tools and processes to address this challenge including land banking (Joseph Schilling & Logan, 2008), adaptive reuse, multi-purpose infrastructure, and consolidation of redundant programs (Fugate et al., 2007). This process is referred to as ‘right sizing’ or ‘smart decline’ rather than smart growth and encourages municipalities to focus on improving the quality of life of remaining residents, rather than trying to grow (J. B. Hollander & Németh, 2011).

Box 13. EPA Product Highlight

Maximizing the Utility of Vacant Land (MURL) is a structured decision-making approach that was developed in support of the City of Cleveland and US EPA Region 5. It is intended to allow community involvement in an open-source, web-based, GIS-linked platform for considering and evaluating options for the re-use of vacant land.

Cleveland is one of many US cities facing a declining population, a reduced tax base, and an expanding inventory of foreclosed and abandoned properties. Land Banks have been used to transfer ownership of these properties to the City or County, with the intent of reusing or repurposing them. A wide range of options exist, including simple yard expansions for a neighboring property. Where multiple, contiguous properties become owned by a Land Bank, an opportunity exists to consolidate and develop a larger parcel toward a new use, such as a park or community garden.

To support these types of decisions for the reuse of land, a Structured Decision Making (SDM) tool was developed and tailored to the site to elucidate fundamental and strategic objectives for the reuse of vacant land. The resulting data is displayed in an interactive, on-line tool (CLEMURL.ORG , which also provides a freely available toolkit for developing a similar platform.

http://digitalcommons.lmu.edu/cate/vol6/iss1/11/

3.2 Influence of Land Use Form and Development on Sustainability

3.2.1 Density

Moderately high population density is widely promoted by planners and smart growth advocates for its putative benefits, which include a smaller footprint of developed land, preservation of agricultural land and open space, less driving, more walking, support for transit systems, and greater opportunity for social interaction. Evidence supports many of these benefits; however, increasingly it appears that density alone is not the critical factor. Instead other elements of urban form influence these outcomes. Recent research suggests that population density, as an isolated factor, has a much smaller impact on travel behavior than once assumed. Job density and centrality, destination accessibility, transit accessibility, and design factors such as intersection density have a larger impact. Drawbacks to higher density include increases in local air pollution, traffic congestion, and allergen concentration.

At the neighborhood scale, density is a necessary, but not sufficient element of sustainable urban form. Literature in the early 2000s used density as a key metric; more recently density is one of a bundle of neighborhood attributes along with intersection density, walkable features, and mixed uses. Loose associations have been noted between density and driving (less driving), walking (more walking), traffic safety (for vehicles and pedestrians), and psychological depression (fewer symptoms)

Although most of the research on density at the neighborhood scale focuses on the urban environment, compact design has been proposed as a valuable strategy for rural towns as well. Bounding rural growth to produce denser villages, also known as “cluster development” or “conservation development” may conserve agricultural land, open space, plus minimize exposure to pesticides (California Governor's Office of Planning and Research, 2010; International City/County Management Association, 2010). Advocates point out that clustered rural development preserves small town charm and contributes to lively social spaces when compared to scattered development along highway routes. Clustering rural development has been reported to reduce impervious surfaces by 10-15% (United States Environmental Protection Agency, 2001).

Potential advantages and disadvantages of cluster development are speculative due to a lack of documentation in the published literature. We address this topic further in Section 6.1 on Decision Science and Land Use Practices section of this report.

Transportation behavior

Urban form, which is shaped by density, is inextricably tied to transportation infrastructure. Essentially, investments in public transit infrastructure allow for greater density of development. Density supports mixed uses, which contributes to the success of public transit and also encourages walking (R. Ewing & Cervero, 2010b; T. Litman & Steele, 2012).

Yet, the establishment of successful, cost-effective public transit requires a minimum threshold of density. The Center for Transit-Oriented Development has identified an absolute minimum of 10 housing units per acre; residential densities of at least 30 units per acre are optimal (Haas, 2010).

Once density thresholds are reached, feedback loops then contribute positively to the development of a robust public transit system and an urban form that supports alternative types of transportation as well. Neighborhoods with a bundle of characteristics including walkability, density, a mix of uses, and transit accessibility have been shown to increase transit use among residents (Mumford, Contant, Weissman, Wolf, & Glanz, 2011; Wood, Frank, & Giles-Corti, 2010) and decrease driving (T. Litman & Steele, 2012).

Neighborhoods meeting these criteria tend to be either older, renovated areas near a town or city center, or a new developments designed to conform to a sustainable development pattern such as traditional neighborhood design (TND), transit-oriented development (TOD), new urbanism, or smart growth. Residents of compact neighborhoods may drive from 5% to 15% less than residents in lower density, more auto dependent locations (T. Litman & Steele, 2012). A neighborhood, city, or town not meeting this threshold is unlikely to successfully launch or sustain public transit.

Energy Use

An inverse correlation of population density with energy consumption for transportation was initially proposed in a 1989 study by Newman and Kenworthy. Gasoline consumption per capita was related to population density in 32 cities worldwide. A 2004 reanalysis of the Newman and Kenworthy data, failed to corroborate the proposed correlation between overall transportation energy consumption and population density, whether measured for the Central Business District (CBD), outer area, or for the whole of the region (Mindali, Raveh, & Salomon, 2004). Subsequent studies based on national data report a marginal association; whereas, a 1996 meta-analysis by the Transportation Research Board reported a 10% increase in density correlated with a 0.5 to 1.0% decrease in VMT as an isolated factor (Transportation Research Board, 1996).

Several meta-analyses confirm that job density, destination distance, transit accessibility, and intersection density all exert a more powerful influence on energy consumption for transportation than population density. These studies show a reduction in VMT of up to 40% when population density, centralization, and high employment are present (X. Y. Cao, Mokhtarian, & Handy, 2006; R. Ewing & Cervero, 2010b; T. Litman & Steele, 2012; Su, 2011).

Air Quality

The effect of population density on air quality has been studied at a regional scale. GHG emissions in denser areas may be lower per capita due to reduced driving and other efficiencies of urban infrastructure (M. Alberti et al., 2007; VandeWeghe & Kennedy, 2007). GHG emissions may also be significantly lower in densely populated cities than in the suburbs. For individuals, however, sulfur dioxide, particulate matter, and carbon monoxide concentrations, and therefore exposures, are higher (Alberti et al., 2007).

Most estimates of GHG emissions are based on local emission data which may be useful for evaluating local exposures and potential health effects, but less relevant to climate effects. Cities with heavy manufacturing show high contributions to GHGs, whereas the cities where these manufactured products are consumed show low contributions. When a carbon footprint is adjusted to incorporate consumption and resident air dispersal in addition to emissions dense, prosperous cities produce a bigger footprint. The effect has been attributed to prosperity, not to density. The higher standard of living of city residents leads to higher consumption and produces a larger carbon footprint (Heinonen, Kyrö, & Junnila, 2011).

Health impacts of density

The social and health consequences of population density are not as commonly studied as are the impacts of density on transportation and the environment. Nonetheless, density has been shown to improve traffic safety —for both vehicles and pedestrians —when compared to sprawling neighborhoods (R. Ewing, R. A. Schieber, et al., 2003). Density is correlated with higher auto emissions at a local scale (Melia, Parkhurst, & Barton, 2011), more traffic congestion (Sarzynski, Wolman, Galster, & Hanson, 2006), and in some areas, higher levels of allergen (United States Environmental Protection Agency, 2007).

Social capital and density

Does crowding have adverse effects on human well-being? Crowded living in high-rise, multi-family housing has been associated with distress (Evans, Wells, & Moch, 2003) and aggression (A. L. Dannenberg, Frumkin, H., & Jackson, R. J., 2011). Sullivan and Chang (in Dannenberg et al, 2011) make a distinction between social density and spatial density. Social density is associated with negative psychological outcomes, whereas spatial density is not.

Social density is typically measured by the number of people per room in a dwelling. Although there is no consensus on the level at which a dwelling becomes too crowded, crowding is generally determined by factors including individual needs for refuge and for coordination of household activities. It is therefore no surprise that negative effects of crowding are more often experienced by low-income individuals (Evans, et al., 2003). One study found a correlation between social density and neuroses beginning at the threshold of 1.5 persons per room in a dwelling (Evans, et al., 2003). The denser neighborhoods in the study relating density with symptoms of depression were still only moderately dense, with less than 12 units per acre. Efficient use of land to avoid crowding is best accomplished ensuring a minimum of personal space rather than developing larger lots.

Evidence suggests that more densely populated neighborhoods have high ratings for social sustainability which is defined by access to services, affordability, social interaction, pride in the neighborhood, and civic participation (Bramley, Dempsey, Power, Brown, & Watkins, 2009).

Another benefit of dense neighborhood development appears to be fewer symptoms of depression in residents (Miles, Coutts, & Mohamadi, 2012). This last association may be due to more opportunity for human interaction in denser neighborhoods. However, residents of equally dense areas were found to have more depressive symptoms when auto commuters were high (ibid).

Equity and density

Dense urban form may have consequences for environmental justice when compared to less dense urban forms. A review of social equity impacts of density in English cities indicated that denser areas improved quality of life for low-income residents Positive aspects were attributed to less segregation and better access to transit (Burton, 2000). However a lack of affordable housing and reduced living space were clear disadvantages. The authors reported weak evidence to support a positive connection between density, access to public services, green space, or jobs.

Diversity and density

Residential density has a complex relationship with diversity. While cities as a whole tend to be diverse places (Talen, 2008), this diversity tends to be in the form of socioeconomically segregated enclaves (Pendall & Carruthers, 2003). An analysis of U.S. metropolitan areas revealed that segregation is lowest in very low density areas, rises in moderate density areas (between about 12 and 14 people per acre), and drops again at the highest densities (ibid). So though traditional neighborhood design (TND) areas, which are denser than typical suburbs, are positively perceived by residents as having more diversity (Lovejoy, Handy, & Mokhtarian, 2010), this may not necessarily be the case in reality.

Obesity, physical activity, and density

Finally, density, as an independent factor, is not associated with obesity or BMI. Combating the public health crisis of obesity and physical inactivity is a national priority and has spurred a significant amount of research on how land use and the urban form contribute to the issue. While there is evidence that land use patterns can significantly affect obesity and physical activity, density alone cannot. A number of studies report no association or only a very small negative association between dense neighborhoods and BMI (R. Lopez, 2004; K. N. McDonald, Oakes, & Forsyth, 2012; Slater, et al., 2010). Similarly, there is no association between density and walking or physical activity (Oakes, Forsyth, & Schmitz, 2007). Dense living may even decrease youth sports participation (Slater et al., 2010). This last association may have more to do with a dearth of recreational facilities than with density in and of itself.

Density, Agglomeration, and Creativity

Cities may foster "agglomeration" efficiencies that allow for the easy sharing of ideas, information, and technology (Muro & Puentes, 2004). Some evidence for this phenomenon exists, as when average labor productivity increases with increasing employment density of counties (Robert Cervero, 2001; R. Ewing, et al., 2001). It has also been hypothesized that the proximity that comes with density spurs innovation. Innovation in this context is typically measured with the proxy of patents per unit area. Research has found a positive correlation between density of creative workers and patenting activity, though not with density alone (Knudsen, Florida, Stolarick, & Gates, 2008). This effect is still under debate, as causal connections have not yet been shown. Other researchers contend that creative workers follow jobs, and the connection between innovation and density is more a factor of the economics and geography of production (Storper, 2009). Further research will help to elucidate this complex emerging field of study.

Financial implications of dense community development

Denser, compact, contiguous development can be cost effective because of reduced costs of infrastructure construction and maintenance (Robert W. Burchell, 2002). This is borne out in numerous studies. Savings have been shown for infrastructure of water, sewer, road and other public services. Studies on this issue typically fall into one of three types:

- *Cost and revenue comparisons of specific developments.* These studies calculate the infrastructure costs and tax revenue per acre for a given development for comparison across developments.

  In addition to savings on infrastructure and service costs, municipalities may accrue higher tax revenue from increased population and business density. For example, Sarasota, FL, on a per acre basis, dense mixed-use development garnered between 4 and 54 times more revenue per acre than a typical strip mall style development (Katz, 2010). A 1989 study by the Urban Land Institute found that a home on a 1/3 acre lot 10 miles from downtown cost taxpayers twice as much as a comparable home on a compact lot near downtown (J. E. Frank, 1989). More recent studies financed by Smart Growth America found that New Urbanist greenfield and infill developments cost about 38% less in upfront infrastructure, have between 10 and 19% lower per unit service costs, and generate between 7 and 10 times higher net revenues per unit than conventional suburban developments (Strategic Economics, 2013). Mixed-use infill, in particular, generated much higher net revenues, around 1,150 times more.

- *Projections of business as usual (BAU) vs. Smart Growth scenarios.* These studies consider how a change in development pattern will affect infrastructure costs. Results vary depending on the location and specific assumptions, but they almost always show the smart growth scenario saves money.

For example, the Maryland Planning Department commissioned a study to estimate infrastructure expenditures for a projected smart growth scenario and a business as usual (BAU) scenario. The report concluded that a smart growth scenario would increase the average density from 1 unit per acre to 2.67 units per acre, would save the county more than 30% in infrastructure expenditures. Project new road construction miles would be decreased by 274% (AKRF Inc, 2011).

Similarly, a model based in Kane County, Illinois, compared the costs of high- density and low-density development. For all four categories of costs considered, high density development was found to be the least costly: developmental cost, individual costs (including property taxes), communal costs (such as roadway maintenance), and social costs (externalities such as air pollution) (Deal & Schunk, 2004).The development density effect was greatest for projected communal costs, which were 98% higher for low density development at the end of the 28-year simulation, and on societal costs, which were also 28% higher for low density development. Multiple projections over 25 to 30 years have shown similar results (Chang, H.C. Planning Consultants, & Planimetrics, 1999; Muro & Puentes, 2004). The Brookings Institution reported that smart growth patterns over a period of 25 years could save governments 11.8% on road building costs, 6% on water and sewer costs, and 3.7% on annual operations and service delivery (Muro & Puentes, 2004).

- *Cost-of-community-services studies.* These studies determine the costs of community services and infrastructure on the basis of land uses, land use patterns, and other factors to calculate an expense-to-tax revenue ratio. A study of 247 counties using 1985 data initially reported that higher density counties had higher per capita infrastructure expenditures (Ladd, 1992); however, more recent studies report contradictory findings. A more recent meta-analysis of 125 such studies found no statistically significant relation between density and overall cost of community services (Kotchen & Schulte, 2009). For similar types of studies, reports of revenues per acre proved a more useful metric for informing community decisions on land use (Strategic Economics, 2013).

Quantitative relations for density

- When household or population density is considered in isolation, a 1% change in density is associated with a mere 0.07% increase in transit use, 0.07% increase in walking, and a 0.04% decrease in VMT (Ewing & Cervero, 2010)
- A 1% increase in intersection density is associated with a 0.23% increase in transit use, a 0.39% increase in walking, and a 0.12% decrease in VMT (Ewing & Cervero, 2010)
- Residents in compact neighborhoods may drive from 5% to 15% less than residents drive in lower density, more auto-dependent locations (Litman, 2012).

- Reductions in VMT of up to 40% have been achieved through integrated smart growth programs that combine density, centralization, and high jobs to housing balance ratios (Litman 2012).
- Optimal density for social sustainability (based on a composite measure of equity, social engagement, and neighborhood satisfaction) occurred around 40-units-per-acre in England (Bramley, et al., 2009)
- The relation between density and segregation follows an inverted u-shaped curve, with segregation peaking between about 12 to 14 people per acre, and dropping again at the highest densities (Pendall & Carruthers, 2003).
- The ratio of all public service expenditures to tax revenues is not significantly correlated with density (Kotchen & Schulte, 2009); however, revenue-per-acre is a function of density and mix of uses.

Best practices and unintended consequences

When conceptualizing density rural and suburban versus Manhattan-style city centers are extremes. An emerging consensus in the planning profession that moderate density appropriate to the context, combined with good design along a gradient, are optimal for density. VMT and transit use, to forest fragmentation and social cohesion, the development pattern is shown to be more impactful than development density alone.

When constructed in an aesthetically pleasing manner with access to nearby parks, residential density up to 36 units/acre has been shown to be acceptable to homebuyers even though the standard suburban density is only 2 to 4 units per acre. Aesthetically pleasing here refers to the inclusion of green infrastructure, mixed uses, and walkability features. (Robert Cervero & Bosselmann, 1994).

For comparison, a study in England reported that the optimal density for social capital was significantly higher at 40 units per acre although neighborhood pride and community attachment peaked at lower densities (Bramley et al., 2009).

A possible unintended consequence of higher population densities is the associated increase in impervious surface cover. Although impervious surfaces may increase locally, increased density may divert development from greenfields, contributing to increases in overall levels of greenspace and lessening of pervious surfaces regionally.

3.2.2 Mixed-uses

Mixed-use design refers to zoning and development for a variety of uses, typically residential, civic, commercial, recreational, and retail. Mixed use does mean mixing industrial facilities with residential and other civic uses.

Evidence presented below supports the assertion that mixed-use developments are associated with a reduction in driving, an increase in walking for transportation and physical activity and, anecdotally, an increase in neighborhood vitality.

Mixed uses and driving

Mixed land uses are consistently associated with a decrease in driving, as measured by either VMT or kcal of fuel burned (R. Ewing et al., 2011; L. D. Frank, Greenwald, Winkelman, Chapman, & Kavage, 2010). In addition, an increase in transit use is promoted by transit-oriented development (TOD). This concept advocates mixed-use and ready access (within ¼ mile) to one or more transit hubs (Mumford, et al., 2011).

Physical activity and mixed-uses

Mixed land uses are consistently associated with an increase in walking for transportation (Duncan et al., 2010), plus an increase in overall physical activity (H. E. Christian et al., 2011; Kerr, Frank, Sallis, & Chapman, 2007; Lovasi et al., 2011; Mumford, et al., 2011; Troped, Tamura, Whitcomb, & Laden, 2011). A statistically significant link between walking and BMI has not been demonstrated (Brown et al., 2009); speculation on the reasons have been presented (Chatman, 2008).

Market research indicates unmet demand for compact, mixed-use developments (Carnoske, et al., 2010; Jonathan Levine & Frank, 2007). In a study based in Atlanta, 70% of the surveyed group expressed preferences for transit and pedestrian friendly environments, and this group was much more likely to want a change from their current neighborhood than those who preferred auto-oriented neighborhoods (Carnoske, et al., 2010).

It can be difficult to isolate the effects of mixed-uses alone, as many studies compare neighborhoods with a bundle of traits such as mixed-use, walkable, transit-oriented, and compact compared to dispersed, car dependent, and single-use. More benefits are associated with a subset of mixed-use developments termed Transit-oriented development (TOD). Residents who live in TOD locations near to light rail stops have been found to have lower (Brown et al., 2009).

Counter intuitively, mixed land use adjacent to parks has been associated with lower park, which may reflect traffic safety concerns from busy streets or the inability to account for walkability as a factor (Kaczynski, Johnson, & Saelens, 2010).

Diversity of activity

Some experts, notably the late Jane Jacobs, promote "diversity of activity" as a more inclusive goal than mixed-use alone, and one that encourages lively and thriving places. This concept typically includes promoting gradual redevelopment to achieve a diversity of housing types, building densities, household sizes, ages, cultures, and incomes. Research based in Chicago provides evidence that a diversity of housing age is positively associated with multiple measures of neighborly social relations (K. King, 2013). There is also evidence to conclude that various methods of increasing income diversity in neighborhoods, including through rental vouchers, increases household safety for voucher recipients, as measured by exposure to crimes against person and property (L. M. Anderson et al., 2003). At the same time, increasing income diversity can be challenging. Incentivizing higher income households to live in areas dominated by lower income households can lead to gentrification, where lower income households are priced out of the neighborhood. However providing vouchers or rent controlled housing options in higher income neighborhoods is often met with resistance by local residents.

Economic return of mixed-uses

While much research exists to support economic impacts of developments considered smart growth, walkable, or compact on measures such as retail revenue and infrastructure costs, fewer were found through this literature search that have looked at the effects of mixed-use controlling for other potentially influential variables. Research comparing per-acre-revenue generation of a variety of land uses in Sarasota County, Florida indicated that that mixed use developments performed dramatically better than residential, commercial, or big box retail stores in isolation. On a per- acre basis, two mixed-use developments brought in from 94 to 142 times the property tax revenue of the local Walmart (Katz, 2010). Increased revenues combined with reduced infrastructure costs for mixed use developments contribute to shorter recovery times for initial investments.

Quantitative relations for mixed-uses

- Residents of mixed-use developments drive from 5% to15% less than residents of single-use neighborhoods (Litman, 2012)
- A 1% increase in the jobs to housing rations leads to a 0.19% increase in walking and a 1% increase in mixed-uses leads to a .15% increase in walking for transportation (R. Ewing & Cervero, 2010b)
- Residents of TOD neighborhoods with nearby light rail stops have lower BMIs (Brown et al., 2009)

Best practices and unintended consequences

Many municipal and county planning departments and non-profit organizations are promoting mixed-uses in support of lively, safe, walkable communities. Examples include the EPA Office of Smart Growth, the Urban Land Institute, the Smart Growth Network, and the Congress for the New Urbanism and The Bay Area Council in San Francisco (National Association of Local Government Environmental & Smart Growth Leadership, 2004). Multiple market feasibility studies indicate that market trends for mixed-use, walkable yield good returns on investments (ibid). Carnoske, et al., (2010) observed that developers sometimes created barriers to more compact, mixed use, residential developments despite growing demand among home buyers, perhaps because of not being attuned market shifts. (Carnoske, et al., 2010).

Growing evidence suggests that a mix of uses combined with other features supportive of walking ,(e.g., safe streets, small blocks, and connected street networks) is promotes benefits in social capital and health (Kaczynski, et al., 2010).

Current studies of the build environment are addressing the impacts of mixing residential, employment, and retail uses, as well as housing types and community services(e.g., libraries, museums, and parks), and diversity of race, income, and age (Talen, 2008).

3.2.3 Transit-oriented development

Transit-Oriented Development (TOD) refers to neighborhoods planned for dense development patterns around a public transit hub. This arrangement is promoted to reduce reliance on automobile use for local trips. TODs are intended to provide transportation options for residents, reduce emissions from automobiles, and decrease traffic congestion. Transit-adjacent development is another approach to accomplish these goals. Both approaches are recognized as potentially useful to stimulate economic development and to encourage affordable housing for several demographic groups. (Jacobson & Forsyth, 2008).

Transit-oriented developments may also encourage walking. (Freeland, Banerjee, Dannenberg, & Wendel, 2013; Lachapelle, Frank, Saelens, Sallis, & Conway, 2011).

The inherent benefits of dense, mixed-use, may be a function of the people who chose to live in such neighborhoods, a phenomenon addressed a number of researchers (R. Ewing & Cervero, 2010a; Lawrence Frank, Bradley, Kavage, Chapman, & Lawton, 2008a).

Box 14. SHC Product Highlight

A report that will provide production functions of ecosystem goods and services for two different neighborhood-scale development scenarios is currently being developed as part of the Tampa Bay Ecosystem Services Demonstration Project (SHC Task 2.1.4.1). One of these scenarios is that of a suburban-style development pattern with ample greenspace; the other scenario is that of a highly walkable neighborhood built in the fashion of older urban areas.

This report may provide useful insights regarding the ecological benefits and costs of Transit-Oriented Development and other neighborhood-scale development schemes.

The potential for TODs to ease the cost of central city housing through lower transportation costs has been recognized(Kitamura, 2009) as well as the potential effectiveness of transportation-based and non-transportation-based development incentives to encourage TOD(Polzin, 1999).

Quantitative relations for TOD

- A synthesis of 14 travel-behavior studies reported that if a neighborhood's density is doubled and all else is kept constant, per capita vehicle trips per capita Vehicle Miles Traveled decrease 5% (R. Ewing & Cervero, 2010a).
- Estimates have been made that if all households in National Ambient Air Quality Standard Nonattainment Metropolitan Statistical Areas no more than 0.1 miles from a transit stop, the total number of automobiles owned by those households would go down 9% and VMT would go down 11%; his reduction is equivalent to a projected impact of a 50% markup in the price of motor vehicle fuel (Kim & Kim, 2004).
- A study of Seattle and King County, WA found the following correlations (L. Frank, et al., 2008a):
- An extra fourth of a mile between someone's home and the closest transit stop is, on average, correlated with 16% less transit use.
- An extra fourth of a mile between someone's job and the closest transit stop is, on average, correlated with 32% less transit use.

3.2.4 Walkability

Walkability is an important measure of sustainable communities and an accepted indicator of the extent to which the built environment is friendly to the presence of people living, shopping, visiting, enjoying or spending time in an area (Abley, 2005). The two primary community design elements found to encourage pedestrians (1) walking access to destinations such as parks, jobs, schools, stores, transit stops, and entertainment, and (2) a dense street grid, which minimizes walking time.

Other design elements conducive to comfortable and safe are the presence of sidewalks, paths, pedestrian crossings, low traffic speeds, street trees, and "eyes-on-the street" views. Walkability is an important concept in sustainable urban design because it impacts human health, social well-being, traffic patterns. Below we highlight the environmental, economic, and human well-being impacts of transportation and land use planning that incorporates walkable neighborhoods.

Attributes of Walkability

Reduced Air Pollution: To the extent that walking becomes a substitute for automobile travel, numerous benefits have been identified including the opportunity to reduce air pollution (L. D. Frank et al., 2006). Frank Litman (2012) estimated that walkable neighborhoods can reduce vehicle miles travelled by 5 and 15% compared to auto-dependent neighborhoods (Litman, 2012). A1% change in intersection density has been correlated with a 0.12% decrease in VMT (R. Ewing & Cervero, 2010b).

Improved Physical Fitness: A number of health benefits and positive social outcomes have been ascribed to walkable neighborhoods. These attributes include increased physical activity (Adams et al., 2011; Carlson, Aytur, Gardner, & Rogers, 2012), increased cardiovascular fitness (Hoehner, Handy, Yan, Blair, & Berrigan, 2011; Sallis, Floyd, Rodriguez, & Saelens, 2012), and lower BMI and risk for obesity (Brown, et al., 2009; Doyle, et al., 2006; L. D. Frank, et al., 2006; Hoehner, et al., 2011; A. C. King et al., 2011) (Sundquist et al., 2011).

Increased physical activity has been credited with lower risk for a variety of non-communicable diseases, including coronary heart disease, type II diabetes, breast cancer, and colon cancer (I. M. Lee et al., 2012).

Increased Social Capital: Residents of neighborhoods that are both mixed use and walkable report increases in social capital, as measured by how well they know their neighbors, participate politically, trust others, and are socially engaged (Leyden, 2003). Other social interaction ascribed to walkability include increases in the average number of friends and associates, reduced crime (with more people walking and watching over neighborhoods, open space and main streets), increased sense of pride and increased volunteerism, reduced risk of depression (E. M. Berke, Gottlieb, Moudon, & Larson, 2007)..

Physical Activity of Children Encouraged: Safe Routes to School, a federally funded campaign promotes to increase the percentage of students who walk to school is also designed to increase physical activity in children. It is in pursuit of these objectives that some argue in favor of establishing or preserving a greater number of "community schools," small institutions located within easy walking distance of a large percentage of their students' homes. However, for a community school to have most of its students walk to class would require residential density levels far above the national average, meaning that most communities must settle for increasing the mode share of walking for school trips without making it the dominant mode. This limitation could potentially be for the best, given that community schools reflect the demographics of the neighborhood. Socioeconomically and racially segregated neighborhoods will have segregated community schools. If a decision is made to promote community schools, elementary schools are the best candidates, as they usually have fewer students than middle schools and high schools, which translate to smaller attendance areas. However, middle schools and high schools may have larger areas around them within which students and their parents choose the mode of walking: a one-year increase in age is associated with 1.4% less probability of getting to school by car and 0.4% more probability of getting to school by walking. With all else being equal, though, in a situation where all students lived a half mile from their respective schools , 34% of students could be expected to walk to school; in a situation where all students lived one mile from school 19% of students could be expected to walk to school. Transportation-system design features that enhance pedestrian safety also have a significant influence on the number of students who walk to school, but not nearly as great an influence as short travel distances (N. C. McDonald, 2008).

An association between walkability and healthy weight is not strong in low socioeconomic neighborhoods (Casagrande, Gittelsohn, Zonderman, Evans, & Gary-Webb, 2011); nonetheless, urban form has been shown to have an influence on weight (X. Cao, Mokhtarian, & Handy, 2007; Kaczynski & Sharratt, 2010; Krizek, 2011; Saelens, Salls, et al., 2012).

Pedestrian Safety is Paramount

The perception of safety and the socioeconomics of the neighborhood have been reported to influence walking more than other variables of urban form (Forman et al., 2008; L. D. Frank, Kerr, Sallis, Miles, & Chapman, 2008).

Economic advantages of walkable places

A number of benefits associated with walkability have economic ramifications ; these can be as straight forward as saving money, improving health, or even increased property values(Active Living Research, Robert Wood Johnson Foundation, & San Diego State University, 2010; Leinberger & Alfonzo, 2012; Pivo & Fisher, 2011). Research based on the WalkScore index of walkability indicated that a 10-point increase in WalkScore corresponded to a 1 to 9% rise in nearby property values (Pivo & Fisher, 2011). Increased appreciation of property values has also been reported (PricewaterhouseCoopers L. L. P. & Lend Lease Real Estate Investments, 2002). When walkability increases the sense of livability in a community, economic benefits can take the form of increased demand for homes (Carnoske, et al., 2010; Jonathan Levine & Frank, 2007; T. A. Litman, 2003) and higher retail revenues (Leinberger & Alfonzo, 2012). Walkable neighborhoods clearly increase property values.

Quantitative relations for walkability

- Walkable, compact, neighborhoods are characterized by 5% to 15% fewer vehicle miles travelled than auto-dependant neighborhoods (Litman, 2012).
- A 1% increase in intersection density has been correlated with a 0.39% increase in walking (R. Ewing & Cervero, 2010b)
- Residents in highly walkable neighborhoods walk an average of 50 min more for transport per week compared to residents in less walkable neighborhoods (Sundquist et al., 2011).
- A 10-point increase in the WalkScore index corresponds to a 1% to 9% increase in property values (Pivo & Fisher, 2011)
- A 5% increase in street connectivity, the mixing of land uses, residential densities, and the ratio of floor area –to-land area is estimated to yield >32% more walking (L. Frank, et al., 2008a).

Best practices and unintended consequences

Active community design to promote walking, biking, and recreation is an emerging practice (Green & Klein, 2011). Emphasis on reducing pedestrian fatalities and providing sidewalks are insufficient to generate walkable space. Jeff Specks (2012) observes that space must be (1) useful, (2) safe, (3) comfortable, and (4) interesting to truly attract walkers. He argues that planners in the United States have focused on safety to the exclusion of other elements critically important to walkers (Speck, 2012). Policymakers can expect an increase in walking and a decrease in driving for neighborhoods that implement some of the many approaches designed to cater to the growing demand for community walkability (Carnoske, et al., 2010).

3.2.5 Urban parks and greenspace

Central Park in New York City is undoubtedly the most famous urban park in the United States. The Central Park was established on 778 acres of city-owned land in the center of Manhattan in the mid-1800s. The site for the park, purchased for $5M, was land characterized at the time as a muddy, rocky swamp unsuitable for commercial development. Today, Central Park has become the site of some of the most expensive real estate in the United States Penthouses at Central Park West have sold for >$50 Million in the past 5 years., whereas the average price per square foot is approximately $4,100 in 2012 (Brennan, 2013).

Figure 13 Central Park, Manhattan, NYC

Thus, Central Park today represents a realization of the most optimistic motivations for communities to invest in public parks and green spaces as community assets and environmental resources. More specifically, parks and greenspaces are reported to garner collateral benefits for human well being, local economies by way of property values and retail revenue, and preserve at least some elements of ecosystem services. There is strong, long standing public and voter support for green spaces (Blaha, 2005).

The American LIVES survey confirms a strong preference for green neighborhoods. Homebuyers largely prefer village greens (85.9%), small parks (84.2%), green courts and cul-de-sacs where children can play safely outdoors (80.5%), and shade trees (74.6%) (Hester, 2006). Moreover, green spaces are important elements of urban design and development, with potential to strengthen the urban core while protecting the fringe from ex-urban development spurred by demand for nature (Blaha, 2005).

Social Benefits of Parks and Green Space

Mental Health & Psychological Peace. Access and exposure to parks and green space has the potential to improve mental and social well-being (Wolf, 2004a) (E. A. Richardson, Pearce, Mitchell, & Kingham, 2013). Psychological studies report that nature restores people's capacity for directed attention, which enables better processing of information and effective stress mitigation (S. Kaplan, 1995) (Hartig & Staats, 2006). These benefits may be especially critical in urban environments, which have been reported to hamper recuperation from stressful actions (Roger S. Ulrich et al., 1991).

In a study of subjects asked to associate different types of places with different mood states, mood was reported to influence interest to be around nature. The authors found that a sense of relaxation was associated with any type of exposure to (Regan & Horn, 2005).

Similarly, the lack of green space contributed to feelings of loneliness Mass et al (2009) and a perceived shortage of social support (Jolanda Maas, Verheij, Groenewegen, Vries, & Spreeuwenberg, 2006).

Increased Sense of Social Well Being. Access to green space has been reported to increase feelings of well-being (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Day, 2008; R. Kaplan, 2001; Frances E. Kuo & Sullivan, 2001a), increase satisfaction with a neighborhood (R. Kaplan, 2001), speed recovery after surgery (Bowler, Buyung-Ali, Knight, & Pullin, 2010), improve social ties (Kazmierczak, 2013), reduce anxiety and depression (Jolanda Maas, van Dillen, Verheij, & Groenewegen, 2009), and reduce stress (Campbell, Wiesen, United States. Forest, United States. Forest Service. Northern Research, & Meristem, 2009; Grahn & Stigsdotter, 2003; Roger S Ulrich, 1999; Wells & Evans, 2003). A study of a citywide effort to green vacant properties found a significant reduction in gun assaults, in addition to a reduction in stress (Branas et al., 2011). No change in property values was found, suggesting that gentrification was not a cause of the change in crime rate.

In a review of the literature, Kuo found that the presence of trees and grass were linked to positive social and mental health indicators, such as "stronger ties among neighbors, greater sense of safety and adjustment, more supervision of children in outdoor spaces, healthier patterns of children's play, more use of neighborhood common spaces, fewer incivilities, fewer property crimes, and fewer violent crimes," (F. E. Kuo, 2003). She explains this relationship by saying, "The presence of trees and well-maintained grass can transform [barren, treeless no man's lands that discourage resident interaction and invite crime] into pleasant, welcoming, well-used spaces. Vital, well-used neighborhood common spaces serve to both strengthen ties among residents and deter crime, thereby creating healthier, safer neighborhoods," (ibid.).

Green space is also linked to better concentration, learning (Moore, 2002), and academic performance (Wolf, 2004a). A school district in California discovered that students in classrooms with the most daylight had test scores 7-18% higher than others and the largest improvements were in classrooms with direct views of nature (Heschong, 2002). Contact with natural features can improve attention in both adults in children, increasing capacity for learning. Greenness exposure may be of particular benefit to children with Attention Deficit Hyperactivity Disorder (ADHD) (Taylor, Kuo, & Sullivan, 2001); views of nature from the home may specifically benefit inner-city girls, who are reported to be less likely to participate in activities outside the home(Spencer, 2002). A study of office workers found that those with interior plants or views of exterior green spaces reported higher job satisfaction and quality-of-life (Dravigne, Waliczek, Lineberger, & Zajicek, 2008).

Noise pollution can have a deleterious effect on both physical and mental health; vegetative features can play a role in reducing atmospheric noise levels from urban activities by absorbing some of the sound (Bolund & Hunhammar, 1999) and by relieving stress induced by surrounding noise (Gidlöf-Gunnarsson & Öhrström, 2007).Vegetation can also shield visual intrusions such as traffic (Bolund & Hunhammar, 1999).

Recreation and Physical Activity. Parks and green space provide opportunities for recreation, especially for children (Bedimo-Rung, Mowen, & Cohen, 2005; Cohen et al., 2007; Giles-Corti B, 2005; Kaczynski & Henderson, 2008; Wolf, 2008). Even momentary exposure to green space on a daily basis can increase the likelihood that a child will engage in moderate to vigorous physical activity. This relationship is even stronger for residents of smart growth communities (Almanza, et al., 2012). Some research shows that the presence of safe, well designed parks close to people's homes is associated with increased moderate-to-strenuous physical activity, especially among women and youth (Kaczynski, et al., 2010). Other studies suggest that the facilities within a park may often be more important in determining physical activity than proximity or number of parks (Potwarka, Kaczynski, & Flack, 2008), or surrounding land use diversity (Kaczynski, et al., 2010). Playgrounds may be the most important determinant of usage for children, (Potwarka, et al., 2008), whereas trails have a strong relationship with park use for physical activity in general (Kaczynski, Potwarka, & Saelens, 2008).

The presence of parks or green space, among other attributes such as a mix of uses, can have a positive effect on the amount that residents walk (Kaczynski & Henderson, 2008).

In addition to causing stress and degrading mental well being, fear of crime and injury can make people reluctant to spend time outdoors during the day, limiting mobility and physical activity (Fullilove MT, 1998; Guite HF, 2006; Loukaitou-Sideris, 2006; P. Tucker, J. Irwin, J.

Gilliland, M. He, K. Larsen, and P. Hess., 2009). The quality of parks and perceived safety of the surrounding neighborhood shape the way people use parks or other open spaces for physical activity. This concern may be particularly relevant for children who conduct most of their physical activity outdoors (Baranowski, Thompson, Durant, Baranowski, & Puhl, 1993; Sallis et al., 1993). Parental perception of safety can have a significant impact on children's outdoor activities, and thus on their overall amount of physical activity (Weir LA, 2006). Women's own levels of physical activity are also impacted by their perception of safety from crime (Eyler et al., 2003; Wilbur, Chandler, Dancy, Choi, & Plonczynski, 2002).

In conclusion, the presence of recreational land use can help to promote regular outdoor physical activity. Needless to say both actual and perceived safety from crime and injury influence utilization of parks and greenspace

Parks, greenspace, and human physical health

Research on the link between green space and health indicate that medical patients recover more quickly and with less use of pain medication when they have access to the natural environment, whether visually or via the out of doors (Terrapin Bright Green, 2012; R. S. Ulrich, 1984; Walch, 2005). Some have hypothesized that physical activity is one contributer to improved health benefits for people with access to parks or green space (Sallis, et al., 2012). Others have noted a positive link between social support and psychological well being for those in green neighborhoods (Jolanda Maas, et al., 2009).

An analysis of the direct effects of physical activity in "natural" versus "synthetic" or built environments indicated a notable difference in self-reported emotions (Bowler, et al., 2010).

Yet another element of study has been the possibility of a link between access to parks or to greenspace to obesity or obesity related health impairments. Bell et al. found that neighborhood greenness reduced the odds that a child's BMI would increase (Bell, Wilson, & Liu, 2008).

A systematic review of greenspace and obesity by Lachowycz and Jones (2011) showed equivocal relations between greenspace and obesity related health indicators (Lachowycz & Jones, 2011).

Green neighborhoods are of particular interest as a possible factor in reducing health disparities in disadvantaged groups. The negative correlation between greenspace and a variety of illnesses is strongest for children and groups of low socioeconomic status (J. Maas et al., 2009). A nationwide study in England found that greener neighborhoods reduced the health disparity between wealthy and disadvantaged groups (Mitchell & Popham, 2008).

While greenspace has been associated with health on the neighborhood and individual scale, this association is not supported at the citywide scale (Elizabeth A. Richardson et al., 2012). Community cohesiveness, sense of place, and safety

The presence of vegetation in common areas of public housing projects was found to be a favorable correlate with use of the space as well as with neighborhood social ties (F. Kuo, Sullivan, Coley, & Brunson, 1998). In a later study, police crime reports were used to map vegetative features and crime rates in an inner-city residential neighborhood. Greener neighborhoods experienced fewer property crimes as well as fewer violent crimes (Frances E. Kuo & Sullivan, 2001b). The data failed to support a commonly held notion that vegetation encourages crime, presumably by providing hiding places.

Vacant lots, on the other hand, are documented to have higher incidences of crime and illicit activity than comparable developed sites (Branas, et al., 2011; Garvin, Branas, Keddem, Sellman, & Cannuscio, 2013). A 10-year longitudinal study in Philadelphia revealed that interventions to green vacant lots were consistently associated with reductions in both gun assaults and vandalism (Branas, et al., 2011). Access to neighborhood parks appeared to be highly valued by urban dwellers in San Francisco. When asked to rank their preferences of neighborhood amenities based on visual displays, Cervero and Bosselmann (1994) found the respondents more willing to accept the higher population densities necessary to justify rail transit service when more public parks were offered in return. Overall, availability of a central park increased the average ratings of the densest neighborhoods, and not having a park slightly lowered the ratings of the less dense ones. Whereas a public park was clearly perceived as a positive amenity, its ability to compensate for density seemed to holdup for a density threshold of approximately 36 dwelling units per acre.

Property values

Many hedonic studies have revealed a positive relationship between housing prices and access to, or distance from, parks (Crompton, 2001), green space, open space, and or water features (McConnell, 2005) (Cho, Poudyal, & Roberts, 2008), (Morancho, 2003), (Kroeger, 2008) (S. T. Anderson & West, 2006; Luttik, 2000; McConnell, 2005), (Active Living Research, et al., 2010). Properties adjacent to parks or open space may have from 7% to 32% higher property values, depending on the proximity and type of park or amenity (Fausold & Lilieholm, 1999). Water features in particular can have a significant effect on house prices (Luttik, 2000). Increases in property values correspond to greater tax revenues for local governments. Rising property values trigger a series of responses, including the sale, subdivision, and development of nearby properties. All of these events have the potential to stimulate gentrification and squeezing out lower income inhabitants.

In a review of the open-space literature, Kroeger notes that the value of proximity to open space is greater when open space is scarce. Proximity to open space, therefore, tends to have a higher value, and a larger relative effect on property values, in more urbanized areas (Kroeger, 2008) consistent with market principles of supply and demand. When demand is high, availability low, then price goes up.

Anderson and West confirm these findings, and add that "the value of proximity to open space is higher in neighborhoods that are dense, near the central business district, high-income, high-crime, or home to many children," (S. T. Anderson & West, 2006). Furthermore, the type of open space that is valued depends on the degree of urbanization, with more highly manicured features preferred in urban core areas (Cho, et al., 2008).

Laverne and Winson-Geidman (2003) analyzed commercial rental rates, which were 7% higher when well designed landscaping was present. Conversely, when landscaping acted as a visual shield, obscuring the business from the street for example, rent prices were negatively impacted. Business owners and merchants often have a negative view of vegetation, resenting the associated debris or visual obstruction from vegetation. Evidence that shoppers value green retail areas, and are even willing to pay more when shopping in greener areas, could therefore be valuable information for merchant groups. Wolf found that shoppers were willing to pay about 10% more for products in shopping areas with trees (Wolf, 2003). In a different study in Athens, Georgia, Wolf found that visitors to a central business district assigned high visual quality ratings to retail areas with a full tree canopy and considered street tree canopy to be an integral amenity in shopping environments (Wolf, 2004b). This has important implications for cities that are looking to revitalize commercial areas.

Ecosystem health and biotic integrity

Urban ecosystems behave differently, and provide different types of goods and services than non-urban ecosystems. A study of oak stands along a rural-to-urban gradient, for example, revealed that urban forests display unique ecosystem structure and function compared to suburban and rural forests (McDonnell et al., 1997). The authors concluded that urban stressors such as air pollution, heavy metals in the soil contributed negatively, whereas heat island effects, and the presence of earthworms (McDonnell, et al., 1997) were among the positive factors affecting urban wooded areas. Urban forests are, essentially, fragmented forest stands, and are likely to have simplified, less diverse species composition, in addition to altered energy flow, nutrient cycling, and hydrological cycles (Marina Alberti, 2005).

Land use practices and landscape interventions to protect resources and habitat can improve ecosystem functioning not just at the local scale, but at the regional scale as by reducing or mitigating habitat fragmentation, encouraging biodiversity and species richness in native species populations, and reducing environmental stressors to flora and fauna.

Many studies have focused on the environmental and ecosystem impacts of vegetative land cover versus impervious cover. Alberti et al. (2007) contend that rather than merely looking at percent imperviousness, variables describing configuration and connectivity of the landscape, such as mean patch size and number of road crossings, can provide a more nuanced understanding of the relationship between landscape pattern and biological condition.(M. Alberti, et al., 2007)

Water Quality, Aquatic habitat, aquatic species

The negative effect of urban landscapes, particularly those with a high percentage of impervious land cover can have a profound effect on water quality (Klein, 1976) (Arnold, 1996),impacts biotic integrity(Miltner, White, & Yoder, 2004) (Yoder & Rankin, 1996), aquatic habitat, and species health (Klein, 1976) (Marina Alberti, 2005), including humans. Immediate upstream land use has a large impact on stream quality (Steedman, 1988). However, the negative effects of impervious surfaces on biotic integrity and fish diversity are lessened by the presence of dense riparian vegetation or when the floodplain and riparian buffer are relatively undeveloped (Miltner, et al., 2004) (Horner, Booth, Azous, & May, 1997). (Miltner, et al., 2004) have concluded that mandatory riparian buffer widths are critical to preserve sensitive areas and minimize hydrologic modification.

The current state for many cities there is that of buried streams. The day lighting of urban streams – opening underground stream channels – has become recognized as worthwhile useful strategy for improving urban ecosystem function and providing greater access to features of nature within urban landscapes.

Plant diversity

There is a positive correlation between plant diversity and the density, size, and age of habitat patches available to plant species within an urban area (Bastin & Thomas, 1999). Shorter distance between patches is also correlated with higher likelihood of species becoming established. Plant diversity and richness is improved in urban settings with larger patch sizes, closely spaced patches, and longevity of patches. There is evidence that a moderate level of urbanization, typically found in suburban areas, is associated with an increase in plant species richness (McKinney, 2008). This evidence can guide urban conservation and habitat conservation efforts to more effectively support urban plant diversity (Bastin & Thomas, 1999). A good rule of thumb land development is that infilling and repurposing of abandoned or vacant land if far more effective for protection of ecosystems than is the converting of natural land to developed landscapes. Put another way, ecosystem productivity and function is best preserved when land remains undeveloped. Improvements in the quality and connectivity of patches within urban and suburban areas could contribute to regional ecological connectivity, and thus to biodiversity, species richness, and ecosystem health.

Urban vegetation, soil and water

Leaf litter and other forest debris create duff on the forest floor that provides habitat for macro invertebrates (worms, insect larvae, etc.), fungi, and microbial communities. These macro invertebrates and microbial communities perform the important ecological function of decomposition of dead plants and animals. The decomposition process releases nutrients for further uptake by vegetation and contributes to the fertility and organic content of forest soils. The resulting decomposition protects soil is an early step in the process of soil biogenesis. Not only is soil created but the potential for erosion is reduced and water infiltration through the soil is promoted. These processes reduce runoff, protect systems from flash flooding, and contribute to ecosystem function. Land becomes better protected from erosion and runoff is reduced. Deforestation removes this litter, exposing soil and increasing erosion, runoff, and sedimentation. These impacts in turn can increase the risk of flooding, and in urban areas, the risk of sewer overflows (Manning, 2008). An additional consequence is that the resilience of the system to disturbance is reduced; vulnerability to natural disasters is increased as well as the recovery time for disasters l.

Bird communities

Bird communities are also affected by living in urban habitats. Certain bird species are too sensitive to disturbance to survive in urban habitats (Blair, 1996). However, for those that can, a variety of factors can improve their survival rate. There is consensus that larger habitat patches support more species, but there are other factors that are important for urban bird communities (Nilon & Pais, 1997). Habitat quality, site design, location within the city, and the unique site history may all be more important than patch size (Ibid).

Residential yards play an important role in bird abundance and diversity. Native trees are important sources of food, shelter, and habitat to migrating birds. For this reason landscaping of developed areas would support wildlife by making choices of native species rather than horticultural cultivars. For example, native desert bird species are more abundant in neighborhoods that are closer to large desert tracts and that have more desert landscaping in the residential yards(Gilbert, 1989). This highlights the importance of promoting natural native habitat in urban areas. While the benefits of habitat patches in urban areas are well documented, the role of connectivity is less well known. . Although habitat corridors have been shown to be a valuable tool in regional settings, only recently has there been empirical evidence to link habitats in urban settings to improve biodiversity (Ignatieva, et al., 2011).

Air quality

Urban vegetation, trees in particular, have positive impacts on air quality, contributing to lower concentrations of particulate matter and lead (Cavanagh, Zawar-Reza, & Wilson, 2009; Francisco J. Escobedo et al., 2008). For urban forests, the area and height of the tree stand makes a difference in the net removal of air pollutants. Particulate matter and lead (210 Pb) concentrations are also lower in the interior of an urban forest compared to the forest edge (Cavanagh, et al., 2009).

Trees improve air quality even when dispersed throughout an urban environment. Evidence shows that particulate matter concentrations are lower in neighborhoods that have a greater percentage of canopy cover (60%) than those with less than 40% cover (Cavanagh, et al., 2009). Escobedo and Nowak (2009) found that in Santiago, Chile, improvements in particulate matter (PM10) concentrations varied between 1.6% in areas with 26% tree cover to 6.1% in areas with 100% tree cover. The magnitude of removal of pollutants by trees varied depending upon season and pollution concentration.

The relationship between trees and air-quality is multi-dimensional. (F. J. Escobedo, Kroeger, & Wagner, 2011).

(Calfapietra et al., 2013). Nonetheless, for urban contexts, choosing low BVOC emitting trees that are well adapted to the local habitat can play an important role in keeping urban ozone levels within safe boundaries (ibid).

While landscape-scale patches are better at improving air quality than smaller scale stands, Escobedo et al (2011) emphasize that the ecosystem services from trees can be beneficial at smaller scales, too. For example, tree stands can also contribute to air quality when located is smaller groupings near schools or hospitals, or in lots without buildings (vacant). Finally, the association between urban forest cover and improved air quality and carbon sequestration is primarily supported by models rather than experimental data (Cavanagh, et al., 2009). A more rigorous understanding of the thresholds and conditions of urban forest cover to achieve air quality benefits could be beneficial especially in combination with regional information on the specific species of trees and the flora and fauna affected by them.

Carbon sequestration

All tree sequester carbon--trees in US urban areas have been estimated to sequester 25.6 million tones of carbon annually (D. J. Nowak, Greenfield, Hoehn, & Lapoint, 2013). Several studies have investigated the c of urban trees to offset CO2 emission. For example, Escobedo et al (2010) determined that urban trees offset between 1.8% and 3.4% of total city-wide carbon emissions. In a study of New England, Zheng et al (2013) estimated that the region's urban and community forests accounted for 8.2% of the net regional forest carbon sequestration. Urban trees can reduce carbon emissions indirectly by providing shade, evapotranspiration, and wind speed reduction. All of these functions can lessen the need for air conditioning or heating, respectively. In a neighborhood in Chicago, 33% shade tree cover was found to have reduced residential carbon emissions by 3.2 to3.9% (Jo & McPherson, 2001). This study highlighted the importance of the placement of shade trees; in the wrong place, shade trees can increase the need for heating in the winter (ibid).

Air temperature & heat island

Trees and vegetation can reduce air temperatures and mitigate the urban heat island effect through two processes. First, trees and shrubbery provide shade, absorb sunlight for photosynthesis and reflect sunlight back to the atmosphere. Second, evapotranspiration, the movement of water from soils through vascular plants followed by release as water vapor from the leaf surface is inherently a cooling process. In combination, the net effect of shading and evapotranspiration can be a significant impact on air temperatures. Air temperatures in urban tree groves can be 9ºF cooler than temperatures over adjacent open terrain. Suburban areas with mature trees can be 4° to 6ºF cooler than new suburbs without trees (United States Environmental Protection Agency, 2008). Yu and Hien (2006) found in a study of two large parks in Singapore (12 hectares and 36 hectares) that air temperatures were cooler not only in the parks, but also in adjacent built environments. For these reasons, green infrastructure is promoted as a key element of climate-resilient urban design (Raven, 2011).

Reductions in peak air temperatures can benefit human well-being, especially in urban environments, temperate climates, during hot summer months. A primary concern is that extreme heat events increase the risk of heat exhaustion, heat stroke, and death, particularly among sensitive groups such as the elderly, infants, and those lacking air conditioning (US Environmental Protection Agency, 2006a). Evidence also links hot temperatures to aggression and violence (C. A. Anderson, 2001; Hsiang, Burke, & Miguel, 2013). Estimates show a 2º increase in air temperature would lead to about 9 more murders or assaults per 100,000 people in the U.S. (C. A. Anderson, 2001). A review of quantitative studies reveals that an increase of 1 standard deviation in temperatures predicts a 4% rise in the frequency of interpersonal violence and a 14% rise in the frequency of intergroup conflict (Hsiang, et al., 2013).

Quantitative Relations for parks and greenspace

- In high minority census block groups in Baltimore, blacks have access to 12.75 acres of park per 1000 people, versus 53.02 acres for whites in low minority census block groups (Boone, Buckley, Grove, & Sister, 2009)
- Properties adjacent to parks have been shown to range from 7% to32% higher property values (Fausold & Lilieholm, 1999).
- In Santiago, Chile, areas with 26% tree cover had particulate matter (PM10) concentrations 1.6% lower than areas without tree cover ; by comparison 100% tree cover showed 6.1% lower PM10levels (Francisco J. Escobedo & Nowak, 2009).
- Carbon sequestration by urban forests offset 18% of the industrial carbon emissions in Hangzhou, China (M. Zhao, Kong, Escobedo, & Gao, 2010)
- Urban trees offset from 1.8% and 3.4% of total city-wide carbon (F. Escobedo, et al., 2010)
- Air temperatures in urban tree groves are about 9ºF cooler compared to nearby open terrain; suburban areas with mature trees are from 4 to 6ºF cooler than new suburbs without trees (United States Environmental Protection Agency, 2008)
- A 2º fahrenheit increase in air temperature is associated with 9 more murders or assaults per 100,000 people in the U.S. (C. A. Anderson, 2001).

- An increase of 1 standard deviation in temperatures predicts a 4% rise in the frequency of interpersonal violence and a 14% rise in the frequency of intergroup conflict (Hsiang et al., 2013)
- Shoppers were willing to pay about 10% more for similar products shopping areas with trees (Wolf, 2003).

Best practices and unintended consequences

Green Infrastructure

The concept of green infrastructure has gained traction in recent years as cities and towns look for ways to reduce the negative impacts of urbanization while accruing the benefits offered by vegetative and natural features in the urban landscape. Reference to these natural and vegetative features as infrastructure is intended to elevate them in importance within planning contexts, so that they are given the same consideration as other types of urban infrastructure that provide important services supporting human life and well-being (McMahon & Benedict, 2003).

Box 15. SHC Product Highlight

A Site-Based Stormwater Calculator, produced by SSWR Task 7.1A is an online calculator that estimates amount and frequency of stormwater runoff from a specific site under a variety of land use scenarios. This tool is an online calculator that will estimate the annual amount and frequency of storm-water runoff from a specific site based on local soil conditions, land cover, and historical rainfall records. This can be simulated under a variety of land-use scenarios. Watershed modelers at the local and state level will find this a valuable tool to identify site-specific land use and green infrastructure improvements can prevent or reduce urban stormwater runoff and its consequences. *http://www.epa.gov/research/waterscience/water-models-data-tools.htm*

The US Environmental Protection Agency's definition places an emphasis on absorbing and/or reusing rainwater where it falls, whereas Benedict and McMahon (2006) define green infrastructure as "an interconnected green space network (including natural areas and features, public and private conservation lands, working lands with conservation values, and other protected open spaces) that is planned and managed for its natural resource values and for the associated benefits it confers to human populations." They stress the importance of strategically planning for the interconnection of green space and natural features in order to maximize their ecological function and therefore their benefits to society.

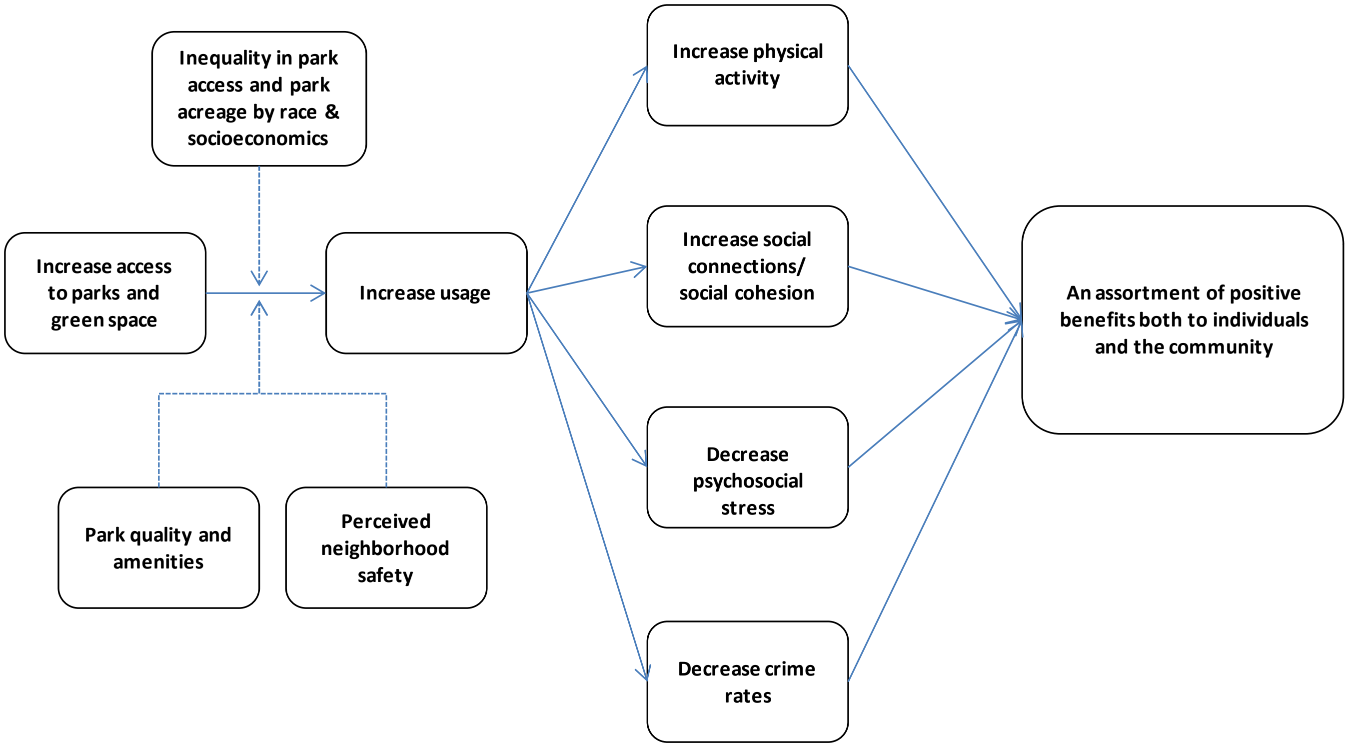
In practice, Benedict and McMahon (2006) recommend that a green infrastructure strategy address this network of features, integrating conservation land and constructed interventions at various scopes and scales. Green infrastructure can include features at the site scale (such as rain gardens and trees) as well as features at the landscape or regional scales (such as city parks or conservation lands). In their discussion of urban forest restoration strategies, Duryea, Binelli, and Korhnak (2000) also stress the importance of including a variety of practices at different scales in order to reestablish structure and function to urban ecosystems.

One of the primary drivers of green infrastructure implementation is the need for stormwater management. Where there is not enough grey infrastructure capacity (e.g. drains, culverts, tunnels etc. to convey stormwater) to service growing populations, or to accommodate large storm events, some municipalities are looking to green infrastructure as a more cost-effective strategy. Green infrastructure can intercept and, in some cases, infiltrate stormwater into the ground, reducing the amount of stormwater that flows into sewer systems, and thus preventing combined sewer overflow (CSOs) or sanitary sewer overflow (SSO) events that discharge untreated sewage into receiving waters. Avoiding CSO/SSO events can reduce the costs of regulatory compliance and capital investments in grey infrastructure (Odefey et al., 2012). For an example for a related practice called low impact development (LID), a 2007 EPA study of 17 case studies found that LID methods incur lower total capital costs compared to conventional stormwater management systems. Savings ranged from 15% to 80% (Environmental Protection Agency, 2007). A more recent study in New York City has demonstrated energy cost savings through an LID approach, though a slow environmental payback time (Spatari, Yu, & Montalto, 2011),

Washington D.C. has proposed incorporating the green area ratio (GAR), a site level metric of green surface cover of a parcel, into the zoning code. It may mandate a minimum proportion of green cover to impervious surface cover on a parcel (Keeley, 2011). However, critics note that such a requirement may create a perverse incentive for low density development on large lots, and penalize high density developments that use space efficiently.

Improving Accessibility & Usage of Parks and Green Space

Accessibility is an important factor in whether parks are used and if benefits are gained from their presence. However, accessibility can differ by race and socioeconomic class, which may contribute to disparities in health-related outcomes, particularly for youth, in areas that don't have access to other resources for physical activity (Godbey, Caldwell, Floyd, & Payne, 2005; Vaughan et al., 2013). Some researchers have concluded that areas with a large minority population and or low socioeconomic status (SES) contain significantly fewer parks and recreational resources than their counterparts (Boone, et al., 2009). Socioeconomic status (SES) is typically measured as some combination of education, income, and occupation. Similarly, some have found inequalities in access to biodiversity, depriving some populations of the sense of wonder and excitement at encountering a wider range of



flora and fauna. For example, residents in lower SES neighborhoods encountered fewer bird species and were less likely to encounter native birds (Gilbert, 1989). Furthermore, the parks that are accessible in low SES neighborhoods tend to be smaller (Boone, et al., 2009; Sister, Wolch, & Wilson, 2010) and higher in crime, which may offset the benefits of access (Cutts, Darby, Boone, & Brewis, 2009).

There are other factors that affect park quality and influences usage and, thus, community-level benefits (Hoehner et al., 2010). These include design, amenities, and acreage (Kaczynski, et al., 2008; P. Tucker, Gilliland, & Irwin, 2007). Aesthetic features, determined by physical design, may contribute to feelings of safety and comfort (Lovasi, et al., 2011). The presence of shade, cleanliness, and infrastructure such as bathrooms, water fountains, outdoor lighting, and play structures have been identified as key factors in influencing parents' choices about where to take their children to play (P. Tucker, Gilliand, & Irwin, 2007).

Park components that attract youth include "sports fields/facilities for movement, walkways and paths, shadow and shelter, trees, water elements, maintenance, renovation, form and size, openness, naturalness and safety," (Gardsjord, 2013) The conceptual framework below captures the human well-being effects of increased access to parks and green spaces.

Figure 14 Conceptual framework capturing the human well-being effects of increased access to parks and green spaces. Dashed lines represent potential mediators

In a study of park usage that tracked over 8000 users, white male children were much more likely to engage in moderate to vigorous physical activity than non-white female children. Significant differences in intensity levels varied by race and gender among teens and adults as well (Kaczynski, Wilhelm Stanis, Hastmann, & Besenyi, 2011).

Approaches are being developed which can help prioritize the development of greenspace and help communities make the most of their park systems. Moseley et al (2013) have published a modeling approach to help communities manage a green network that meets the needs of both transportation and leisure users and aims to improve accessibility in areas of higher social deprivation. Kaczynski et al (2012) have developed a Community Park Audit Tools (CPAT) that communities can use to assess how effectively their parks promote physical activity. The tool includes measures of accessibility, amenities, quality, and safety (ibid). The tool built upon existing park audit tools such as the Environmental Assessment of Public Recreation Spaces (EAPRS) to provide a tool that assessed youth needs, was user friendly, and was developed and tested with community stakeholders in order to ensure it was meaningful and applicable to a diverse group. Finally, The Trust for Public Land has published a guidebook that highlights the most important urban park practices to promote health (Harnik & Welle, 2011).

Urban Forestry

Successful urban forests depend on good design strategies. Ideally trees are placed and spaced so that they don’t interfere with visibility, traffic signals, and existing municipal infrastructure (Burden, 2006). Sufficient space and soil quality can prolong the truncated lifespan of urban street trees as well as reduce sidewalk heaving as crowded roots stretch out between compacted soil and sidewalks (Buscaino, Upchurch, Whitlow, & Wellborn, 2008). Information to guide both property owners and maintenance personnel to plant “the right tree in the right place” can maximize benefits of energy savings, shade, beauty, air quality, and stormwater management. Another consideration for residential trees is to select species that reduce burdens of allergens, maintenance requirements, and damage from limb breakage, and are not likely to interfere with power lines (Lipkis & Lipkis, 1990; McPherson, 2003). Resident satisfaction with a street or yard tree is likely to be greater if the vegetation is planted by an occupant. When residents join neighbors to plant trees, there is the additional benefit of building social capital that accrues when neighbors work together toward a common goal (Sommer, Learey, Summit, & Tirrell, 1994).

Some organizations, such as Tree People in Los Angeles, Boston Tree Party, and Casey Trees in Washington DC, have fruit tree programs in addition to their other tree planting programs. These programs aim to increase the numbers of fruit trees in urban areas as a means of producing food within the urban ecosystem, especially to low-income residents (Casey Trees, 2013; The Boston Tree Party, 2011; Tree People, 2013).

When urban trees must be cut, utilizing them for wood products reduces waste, reduces resource demands, and reduces costs that municipalities or landowners would otherwise pay to remove and dispose of unwanted trees (Bratkovich, 2001).

Full accounting of costs and benefits

Without full accounting for the pubic costs and benefits of parks and other greenspace, these public resources are often undervalued and may be usurped for commercial purposes, thus allowing private land-use to overcall the provision for quality public space. Lambert (2007) argues that the asset values as well as the co-benefit values of parks should be accounted for in civic balance sheets. Valuations of parks with monetization of collateral benefits would make it possible to all allocate resources for their maintenance. The Trust for Public Land provides one example of a more comprehensive valuation of the parks in New York's Nassau and Suffolk counties, incorporating quantitative values for reduced costs of government services; recreation & tourism; agriculture; government revenue and cost savings; as well as a qualitative discussion of un-quantified co-benefits (The Trust for Public Land, 2010). The study concluded that parks and open spaces have a much lower net cost-to-government services-per-acre ratio than residential development. In addition, parks contribute to a large recreation and tourism industry, as well as provide many other benefits to society that could not yet be quantified.

3.2.6 Regional accessibility

Accessibility may be measured at either a local/neighborhood scale or at a regional scale. At the local/neighborhood scale, accessibility may be represented as the average distance from a person's home (or place of work) to the nearest store (or other destination). At the regional scale, common measures include the distance from a given point to the nearest central business district (CBD) and an inventory of the number of jobs or other destinations that can be reached from a given geographical point within a given period of time (R. Ewing & Cervero, 2010b). Travel behavior impacts of regional accessibility

The accessibility of destinations is the single most important factor shaping people's travel behaviors. After accessibility ,separate measures of intersection density, land use diversity, transportation network design, or proximity to public transit can all be influential in shaping transportation decisions (R. Ewing & Cervero, 2010b).

Box 16. Decision Support Tool

i-Tree Urban Forest Assessment Applications provides a suite of tools at different scales to help urban forest managers quantify ecosystem services provided by community trees, including pollution mitigation, carbon sequestration, water quality and stream flow, shade, and aesthetic benefits. The tools were developed by the US Forest Service and are available here: *http://www.itreetools.org*

The amount of time in transit (Lawrence Frank, Bradley, Kavage, Chapman, & Lawton, 2008b) trip frequency, socioeconomic factors are also predictive., Trip length, however, is influenced by land use and infrastructure (the "built environment") to a greater extent than by socioeconomic variables (R. Ewing & Cervero, 2010b).

More than anything else, regional accessibility has a substantial influence on VMT, which itself is a driver of many different sustainability outcomes: energy use and greenhouse gas emissions

If a dense, mixed-use, highly-walkable development is created in a remote location, it will still generate more private automobile travel than if it were located in an urban core. In urban core neighborhoods, a greater variety of trip destinations are near enough to be reached by non-motorized modes.

A 1% increase in accessibility of employment locations by automobile has been associated with a 0.2% decrease in vehicle miles traveled. The authors reported a stronger correlation between VMT than any other aspect of the built environment (R. Ewing & Cervero, 2010b).

Economics, accessibility, and transportation

Accessibility drives development. In general, destination accessibility promotes economic development; therefore, policies to increase destination accessibility can positively affect the economy. Not surprisingly, the economic benefits of destination accessibility are greatest in places that are in close proximity to transportation infrastructure, meaning that such places are particularly good candidates for increased development. However, the benefits of locating in these places are offset by various economic disbenefits that come from building near a major transportation corridor, such as noise pollution and air pollution (Hof, Heyma, & van der Hoorn, 2012; Jha & Kim, 2006).

Accessibility, travel time, and social interaction

In those places where regional accessibility is low, the longer travel times that people consequently experience can have numerous negative effects on their lives. If someone has to spend a large percentage of their time traveling, they have less time to spend with their family, less time for social interactions, and less time for exercise and recreation, especially if the low destination accessibility of the region not just increases the durations of the trips people need to make but also the durations of their discretionary trips, which are consequently make fewer (Besser, Marcus, & Frumkin, 2008a; T. J. Christian, 2012a, 2012b; Dickens, Richards, Greaves, & Campbell, 2011; Fujiwara & Kawachi, 2008; Holt-Lunstad, Smith, & Layton, 2010).

Quantitative relations for regional accessibility

- A 1% increase in an index of the accessibility of employment locations by automobile reduces Vehicle Miles Traveled (VMT) by 0.20% (R. Ewing & Cervero, 2010b)

- On average, a 1% increase in parking spaces per 1000 employees in the central business district of a region decreased transit boardings per capita per year by 1.27% in a study of data from numerous major cities around the world over a timeframe of multiple decades, if all else is assumed constant and allowance is made for the fact that this elasticity value varies with the size of the input variable (Sinha, 2003).

Unintended Consequences

Tradeoff of exposure to air pollution

Greater destination-accessibility is able to help reduce overall air pollution from automobiles by reducing Vehicle Miles Traveled. However, locations that are within a short travel time of a large number of destinations are very often in close proximity to high-volume roadways, where concentrations of motor-vehicle-generated air pollution are the greatest. Therefore, people who live, work, or go to school in locations that have high destination-accessibility may be at greater-than-average risk of experiencing the negative health effects of near-road pollution (Ghosh et al., 2012). This includes approximately 30-45% of people living in urban areas in the United States (Y. Zhou & Levy, 2007).

Amongst the pollutants found in high concentrations near roadways are nitrogen oxides (NOx), carbon monoxide (CO), particulate matter (PM), and volatile organic compounds (VOCs). In recent decades, technological changes have reduced the quantities of some pollutants that vehicles emit per mile of travel, but this benefit has been offset by increased rates of driving (Dallmann & Harley, 2010). Recent research has highlighted the potential of on street parking to act as a buffer to protect pedestrians from roadway air pollutants (Gallagher, Gill, & McNabola, 2011).

Although links between exposures to traffic-generated pollutants and adverse health effects have been established (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010), uncertainty remains about what level of exposure to near-road pollutants causes these adverse effects and about the important metrics in determining potential risks, such as the distances away from roadways and/or traffic volumes of concern. This is because the transport of near-road pollutants from their sources is affected by such factors as building locations and design, topography, wind speed and direction, and roadway design features (Baldauf et al., 2009).

Tradeoff of exposure to noise pollution

Because locations with great destination accessibility are often near high-volume roadways, residents may be exposed to elevated levels of noise from motor-vehicle traffic. According to studies, there is an association between exposure to noise from automobile traffic and negative health outcomes. For more on these studies, see subsection 3.4.7 of this synthesis paper, on the impacts of roads as a land use.

Impervious surface

In remote locations, where destination accessibility is typically low, transportation-related land-use per-capita at the regional scale increases, on account of more transportation infrastructure being required to link dispersed structures (Brabec, 2009). Transportation-related impervious land cover exerts a large hydrological impact because it is comprised of connected areas that drain directly into streams (J. G. Lee & Heaney, 2003; T. R. Schueler, 1994). Consequently, built-up pollutants and flows of stormwater directly enter surface water systems, with potential to reduce both drinking-water quality and functioning of aquatic ecosystems. However, the percentage of overall land cover that is impervious in rural areas is still lower than in urban and suburban areas. For more information on transportation-related impervious surfaces, refer to subsection 3.4.7 of this synthesis paper, which discusses the impacts of roads.

Water infrastructure implications

In many metropolitan areas, highways and commuter transit lines have improved accessibility to remote locations. As a result, exurban leapfrog developments are created, whose travel activities are oriented towards a particular urbanized area but which are separated from the metropolitan area by a significant expanse of undeveloped land (R. H. Ewing, 2008). Often, these developments are too remote for it to be practical to connect them to the water and sewage systems that serve the nearby urbanized area. Consequently, these developments either come to be served by small community water and sewage systems or by privately owned wells and septic tanks. Because water and wastewater systems are difficult to change, these small-scale systems may remain in place in leapfrog development after the nearby urbanized area can expand to abut against the once remote parcel. Small-scale water and wastewater systems tend to be based on technology more prone to leakage and seepage. Monitoring for well water contaminants is at the discretion of the owner in most cases. Microbial and toxicant intrusion to drinking water may remain undetected and unremedied for years (O. o. R. a. D. U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 2007; O. o. R. a. D. U.S. Environmental Protection Agency, Office of Water, 2002).

3.2.7 Compact development pattern

In the United States, urban land is projected to increase from 3.1 % in 2000 to 8.1 % of the country in 2050 under a business as usual scenario (D. J. Nowak & Walton, 2005). If a more compact development pattern is applied widely, the amount of open space converted to urban development could be significantly reduced.

Compactness refers to a development pattern that is contained and contiguous. Evidence shows that compact, centered, cities that have established transit systems reduce VMT and increase transit ridership, which also decreases overall emissions on a regional basis. The paradox of this phenomenon is that dense, compact cities also support higher population densities and can increase congestion. This effect counteracts and may even surpass the emission reduction due to lower VMT at a local level, leading to equal or increased emissions within the city, even as emissions in the region as a whole go down. Some researchers have attempted to address this problem by studying how design can impact the dispersion of pollution, reducing pollution hot-spots (Jenks, Burton, & Williams, 1996).

One objection to compact development is that the trend toward lower density single-use residential neighborhoods originally stemmed from desires to escape the overcrowding of cities. This concern is addressed in two ways, 1) advances in sanitation, ventilation, and architecture that allows for more light and airy spaces reduce the discomforts of denser living, and 2) the residential densities advocated by most practitioners today remain very moderate (at between 7-12 units per acre for single family homes).

Compact development, land conservation, and extreme heat events

There are many environmental benefits of a compact development pattern. Land conversion occurs at a slower pace given the same growth in population, protecting rural and agricultural land and open space (McLaren, 1992; United States Environmental Protection Agency, 2001). In turn, land preservation supports increased biodiversity (United States Environmental Protection Agency, 2001). Finally, there is evidence that compact cities experience fewer extreme heat events than dispersed cities. The sprawling metropolitan regions have experienced an increase and even doubling of extreme heat events when compared to the most compact metropolitan regions (between 1956 and 2005) (Stone, et al., 2010).

Congestion and compact development

High traffic congestions and increased use of impervious surfaces are common consequences of compact development (Melia, et al., 2011; Sarzynski, et al., 2006). Fortunately, compact urban areas that have short distances to transit stops may well ameliorate the congestion (R. Ewing & Cervero, 2010b). It is possible that compact development increases the proximate impervious surface cover as well. However an increase in impervious surface cover per unit area may not be detrimental, if the impervious surface per capita is reduced overall in the region. Additional research is necessary to characterize this relation.

Impervious surfaces and compact development

Compact development typically leads to higher impervious surface cover than more disperse developments; however, another important dimension to consider is the *per capita* ration of impervious surface cover. For example, a suburban neighborhood will have relatively low percent total impervious area (PTIA) compared to an apartment building, however to house the same number of people in a suburban development will require impervious surfaces to extend over a greater swath of land.

Compact development concentrates higher PTIA over a smaller area, which may reduce the region wide levels of impervious surfaces, but may allow very high impervious surface cover in very populated areas. For the purpose of comparing alternative development patterns, a *per capita* measure of impervious surfaces may be more meaningful. Research to quantify the advantages and disadvantages inherent in this tradeoff would be a valuable contribution to the literature.

Energy consumption of compact development

One benefit currently under debate is if, and to what degree, compact development is associated with energy consumption. Research suggests that moderately compact development may be the most sustainable form. This form may have the lowest overall energy usage, and may relieve traffic congestion whilst still supporting a robust transit system. A comparison study of several Norwegian cities found the moderate density cities to have the lowest residential energy consumption levels, including both transportation and household energy use (Holden & Norland, 2005).

Household energy use varies by housing type, however the difference between single family home energy use and row houses and multifamily housing has declined in more recently built homes in the Norwegian cities studied, as energy saving methods became commonplace in single family homes. The differences in overall energy usage were more affected by travel. Both moderate and high density areas consumed less energy for everyday transport, due to shorter distances and transit use. Higher energy usage in the densest cities was primarily due to higher wealth and therefore increased consumption, particularly of leisure travel by plane. It's not clear whether this is due to residents' preferences or due to compensating for a lack of access to outdoor recreation on an everyday basis. The fact that residences with access to a garden or yard consume less energy for leisure travel by car or plane suggests the latter may be true. The link between higher wealth in the densest cities and increased consumption and carbon footprint has been replicated in Finland (Heinonen, et al., 2011). However it is an opportunity for additional research, particularly to see if the relationship holds in the U.S. context.

Compact development and walkability

Compact development has benefits for human well-being that are more difficult to quantify than single dimensional indicators, such as walkability A compact development pattern is consistent with neighborhood walkability and a mix of uses. Other characteristics of walkable neighborhoods include street connectivity and resident density alone were not associated with body mass index (BMI) (K. N. McDonald, et al., 2012). Less sprawl is consistently associated with more walking (I. M. Lee, Ewing, & Sesso, 2009). However moving from a county high on a sprawl index to a more compact area is not associated with an increase in walking or a decrease in BMI (ibid).

Commute times in compact development

Commute time also is related to compact development, but the essential factors are not always clearly identifiable. As mentioned above, compact development readily leads to traffic congestion. However commute time is also affected by distance and mode choice, and walking, bicycling, or taking transit can be significantly quicker in compact cities. Yet there may be many options available to alleviate the downsides of compact urban forms. Some studies have found a decrease in commute time(L. D. Frank, et al., 2010), others no correlation at all (R. Ewing, Pendall, Chen, Trb, & Trb, 2003). What is clear is that individuals with shorter commute times enjoy higher levels of social capital, as measured by the frequency of social trips (Besser, Marcus, & Frumkin, 2008b).

Housing affordability in compact cities

The success of municipal regulations to achieve compact development and its impact on the supply of affordable housing is of current interest as communities seek to realize the benefits of compact development.

Four main points dominate the literature on this issue.

First, both traditional zoning and urban growth controls have the potential to raise housing prices. Traditional zoning often enforces low-density single family homes, which reduces the supply of homes and can raise prices (Nelson, Pendall, Dawkins, & Knaap, 2002).
Second, although planning policy can influence housing prices, market demand is the far greater driver (C. J. Dawkins & Nelson, 2002; Nelson, et al., 2002; Phillips & Goodstein, 2007).

Third, affordability can be impacted if strict growth controls are implemented in quickly growing regions without any accompanying changes in zoning, regulations, or regional planning. This appears to be what happened in Petaluma, San Jose, and other areas of California (Nelson, Pendall, Dawkins, & Knaap, 2002).

Finally, growth controls to increase allowable residential density and housing type mix whether implemented with or without regional planning and zoning reforms have no noticeable impact on the availability of affordable housing. Evidence from Portland, OR, indicates that while the Urban Growth Boundary (UGB) may have increased property values, the attendant increase in density led to an increase in the overall supply of housing units, and therefore no net change on housing affordability (ibid). The rise in housing prices was attributed to increase in demand.

Smart growth and job creation

Compact development may benefit job creation in the local economy. One study of metropolitan areas with smart growth measures in place concluded that more construction related jobs were created and than in areas without growth management policies (Mattera & LeRoy, 2003).

There is debate over whether and how compactness would affect the cost of infrastructure and community services to taxpayers. This issue is addressed in more detail under the section 3.2.1 on density.

Quantitative relations for compact development

- From 30% to 60% of commuters use public transit to central location use transit, compared to 5% to15%utilization of public transit to dispersed locations(T. Litman & Steele, 2012).
- The most sprawling metropolitan regions experience an increase in extreme heat events that more than doubles the incidence for compact metropolitan regions (between 1956 and 2005) (Stone, et al., 2010)

Best practices and unintended consequences

Despite the debate over the magnitude of market demand for compact development, the notion that a compact city form is consistent with principles of sustainability is rarely questioned. Michael Neuman (2005) points to the many professional and political institutions that support this compact city design, including the Urban Land Institute, the American Planning Association, the President's Council on Sustainable Development, the European Environment Agency, the United Nations, and the National Research Council.

The role of compact development in achieving sustainability at a regional scale is relatively unexplored. Neuman (2005) notes that many insular compact developments are still primarily residential, and are often exist at the periphery of established metropolitan areas.

This growth in extraurban satellite communities requires commuting to work and to shop, and may be an enabling factor for promoting sprawl. Excessive growth restriction in a growing area can spur leapfrog development, which bypasses the buffer area and shifts development into a neighboring jurisdiction. This can lead to even longer commutes with concomitant increases in vehicle emissions.

When regions develop in cooperation, they may be able to limit leapfrog development and restrict expansion to the periphery of a densely populated area. Infill developments between the central city and this peripheral development may sometimes be more densely populated than the areas around them, challenging the traditional notion of sprawl. Sprawl is in part defined through time. If disperse, leapfrog development quickly gives way to dense infill, it may not be sprawl, but simply the process of dense growth into new areas. Whereas a moderately compact city may be consistent with the concept of sustainable urbanism, it's also been noted "There is no such thing as a sustainable city (Neuman, 2005)." To the degree that cities rely on the countryside for resources, food, and trade, cities and rural areas are interdependent. The well being of one cannot be readily or accurately extricated from the other.

3.3 Impacts of Land Use Types on Sustainability

3.3.1 Residential

Housing consumes land, energy, water, and produces GHG emissions. Housing is also an important contributor to human well being, although it can be a means to create and perpetuate segregation. Where one lives determines accessibility to a host of services, amenities, education, jobs, and more. Housing accounts for approximately 4% to7% of all the total land area in the United States, when including rural residential lots (Emrath, 2006). As such, it is an important contributor to the conversion of open space and agricultural land to developed uses. From 1980 to 2009, the number of residential buildings has steadily increased from 81.6 to 113.6 million units (EIA, 2012). Along with an increase in the number of residential buildings, the size of the residential buildings has markedly increased. For example, homes built since 1990 are 27% larger than those built in previous decades (EIA, 2012). However the trends in housing are not unidirectional. Although the number and size of residences has steadily increased, the median lot size has steadily decreased. As an example, the median lot size in 2009 was 0.26 acres compared to 0.42 acres in 1991, a 38% decrease in land area (BOC, 1991, 2009). This indicates a gradual increase in housing density, perhaps an indication of the increasing demand for more traditional neighborhood developments. In fact, more evidence supports the idea that smart growth principles are becoming more popular. In nearly 75% of large metropolitan areas between 2000 to 2009, infill housing development (new housing in previously developed areas) grew as a share of all new housing (US Environmental Protection Agency, 2012b).

However, smaller lots may not actually indicate a smaller per capita footprint as homes are sheltering fewer people on average. Over several decades, the average number of people per household has steadily decreased since the 1940s although the average has markedly leveled off, potentially due to the economic downturn and the shift to multi-generational households (BOC, 2011). And though infill housing is becoming more prevalent, Greenfield home construction still accounts for the majority of all new homes on almost all cities (US Environmental Protection Agency, 2012b).

Residential resource consumption

Housing is an important contributor to land consumption, energy usage, GHG emissions, and water usage. A study based in Toronto on 1990 data found that residential buildings accounted for 31% of all GHG emissions (VandeWeghe & Kennedy, 2007). A model based on Australian cities estimates that 40% of all water related energy usage in a city is used by the residential sector, with 31% going towards heating water (Kenway, Lant, & Priestley, 2011).

From 1980 to 2009, average household energy consumption has surprisingly decreased from 114 to 89.6 million Btu (EIA, 2012). At the same time, electricity used for electronics and consumer appliances has markedly increased. The share of residential electricity used for electronics and consumer appliances has almost doubled in the last three decades, increasing from 17% to 31% (EIA, 2012). Although home sizes and electronic use has increased, improvements to the building envelop (e.g., better insulation, double-pane windows), energy efficient home heating/cooling systems, as well as improvements to the appliances used in residences (e.g., water heaters, refrigerators) have decreased the average energy consumption per home.

Technology improvements have also narrowed the energy efficiency gap between multifamily housing and single family housing since 1980. Single family homes built since 1985 use only 20% more energy per capita than multifamily, and continue to get more efficient (Holden & Norland, 2005). Residential water use has also become more efficient. Despite population growth in Toronto, residential solid waste and wastewater decreased in absolute terms between 1987 and 1999 (Sahely, Dudding, & Kennedy, 2003). Such rapid increases in efficiency lead some to believe that with more technological advances, single family homes may become just as sustainable a choice if set into a decentralized, but compact context that help reduce trips and trip distances (Holden & Norland, 2005).

Residential land use impacts on water quality and quantity

However energy efficiency does not tell the whole story. Residential uses also consume a large portion of the nation's land, increasing impervious surface cover. In this way residential land use significantly contributes to urban heat island formation and surface water pollution and runoff. Perhaps counter intuitively, low density single family style housing, despite providing more lawns and trees, results in more impervious surface cover for the same occupancy capacity than higher density housing (Stone, 2004). Furthermore, the ubiquitous lawns exact a price in water quantity and quality. Lawns require irrigation, which drives up water usage, increases runoff, and reduces the community's capacity to manage flooding (A. Schneider, et al., 2012). Researchers estimate that the projected rate of urbanization in the US Corn Belt cities is causing an expansion of turf grass in residential areas that leads to an increase in runoff of 15–48% (ibid). In addition, GHG emissions produced are significantly lower in residential areas in the city center than in suburban areas, when accounting for per capita transportation emissions and building electricity use, the report finds that overall, residential areas in the city center produce significantly less (VandeWeghe & Kennedy, 2007).

Residential land use also impact water supplies by impacting both ground water and surface water. USGS (Metz, 2007) found that detections of volatile organic contaminants increased with population near water supply wells. Generally the highest detections were in residential land use areas. Potential impacts from septic systems, lawn and garden fertilizer, large scale pesticide application, animal waste, sanitary and combined sewer overflows, storm water runoff, vehicle washing, small quantity chemical use, and above and below ground storage tanks highlight potentially problematic issues related to land use (US Environmental Protection Agency, 2002a). When contaminated runoff flows into recreational water bodies, illness rates rise among beach users (Colford et al., 2012; Heaney et al., 2012; Wade et al., 2010).

Residential segregation

The spatial segregation of neighborhoods by socioeconomic divisions is increasingly common and a major concern for community public health advocates (L. M. Anderson, et al., 2003). In 1990, about 18% of poor metropolitan residents lived in areas with at least a 40% poverty rate, reflecting a high degree of segregation (ibid). Residential segregation causes health disparities among races and classes. Segregation concentrates disadvantages through constraining socioeconomic advancement (education, employment, home ownership), increasing exposure to crime, environmental hazards, and inferior public services, including health care services (Acevedo-Garcia, et al., 2008; Ahmed, Mohammed, & Williams, 2007; J. D. Brender, Zhan, Suarez, Langlois, & Moody, 2006; Dark, Williams, & Barnett, 2004; White, Haas, & Williams, 2012; Williams et al., 2012).

To combat residential, racial, and economic segregation, local and federal government agencies use approaches including rental vouchers, mixed income housing projects, and affordable housing quotas. Rental vouchers or other tenant based financial assistance has clear research supporting the benefits to tenants including reduced exposure to crime and neighborhood disorder. Research with control groups is needed to properly evaluate the effectiveness of mixed income housing projects (L. M. Anderson, et al., 2003). However, there is evidence to suggest that reducing neighborhood poverty impacts resident well being. Data from a randomized housing mobility program, *Moving to Opportunity*, has found that moving from a high poverty neighborhood to lower poverty one improves physical and mental health and subjective well being over the course of 10 to 15 years (Ludwig et al., 2012). However the move did not improve residents' economic self-sufficiency.

Housing affordability

Housing affordability is a concern for many households therefore efforts to desegregate housing must be sensitive not to increase property values to such a degree that it reduces the supply of affordable homes. In 1997, 14% of U.S. households were classified as having critical housing needs, meaning they spent more than 50% of their income on housing, or lived in very poor conditions (National Association of Home Builders, 2001).

See sections on Neighborhood Density and Mixed-uses for information on how the form of neighborhoods and their amenities impact human well being.

Community budget impacts of residential land use

As opposed to commercial and industrial development, residential development is almost always revenue negative for local governments. Reigning in the costs to be closer to revenue neutral is a powerful way for local communities to balance budgets. The American Farmland Trust estimates that the median cost of servicing residential uses in the U.S. is

$1.15 for every dollar of revenue (AKRF Inc, 2011). Areas such as Queen Anne's County, MD that are predominately more traditional denser single family neighborhoods have median service costs closer to $1.02 per dollar of revenue. In this context, residential density is still low; the American Farmland Trust compares figures for between 0.2 and 4.5 units per acre (ibid). The National Association of Home Builders confirms this general sentiment, saying that "because they are built at higher densities, multifamily homes reduce local governments' capital and operating costs." A 1973 study estimated that, in British Columbia, multifamily homes at 30-units-per-acre required almost 70% less in annual public service expenditures than single-family homes at three-units-per-acre, at $1,647 and $2,361, respectively (National Association of Home Builders, 2001).

Quantitative relations for residential uses

- Residential buildings accounted for 31% of all GHG emissions in Toronto (VandeWeghe & Kennedy, 2007)
- 40% of all water related energy usage in a city is used by the residential sector, with 31% going towards heating water (Kenway, et al., 2011)
- The median cost of servicing residential uses in the U.S. is $1.15 for every dollar of revenue; moderately denser residential areas (4.5 units per acre) bring service costs to around $1.02 per dollar of revenue (AKRF Inc, 2011).
- Expansion of residential turf grass in growing midwest cities may require an additional 8–105million m3 of water use annually and increase runoff by 15–48% (Schneider et al., 2012)
- A decline in neighborhood poverty of 13 percentage point "increases subjective well-being by an amount equal to the gap in subjective well-being between people whose annual incomes differ by $13,000" (Ludwig et al., 2012)

Best practices and unintended consequences

The role of zoning and other governmental involvement in the creation of suburban sprawl is controversial. Some claim that the federal government subsidizes low density housing (Danielsen, et al., 1999). Others point out that zoning for minimum lot sizes contributes to forcing a dispersed development pattern in many suburban and rural areas (J Levine, 2005). An alternative explanation is that development patterns reflect consumer preferences rather than regulatory mandates (Kopits, et al., 2012).

A study in Maryland compared actual lot size to the allowable density under zoning regulations and reported that average lot sizes were typically well below allowable densities and sometimes even less dense than permitted (Kopits, et al., 2012). In other words, rather than building at the maximum density allowed in the area, which would indicate that regulations were artificially keeping densities low, most actual densities were lower than allowed. However, the authors acknowledge this effect was less pronounced in the low density zoned areas. They conclude that the willingness to pay for larger lot sizes has decreased by 17% between 1985 and 2000 in the study area (ibid).

The authors also report that many consumers are willing to accept the tradeoff of smaller lot sizes for larger house sizes. This research suggests that if communities wish to increase residential compactness, merely raising the allowable density may be insufficient, and minimum density zones may be necessary. Consumers generally appear to prefer larger lots in suburban settings, there is unmet demand for higher density transit-accessible housing, and good evidence that even those who initially prefer lower density housing, will accept higher densities when accompanied by amenities such as pocket parks, street trees, and shorter commutes (Danielsen, et al., 1999).

A number of residential zoning and regulatory reforms are advocated to promote well-being in disadvantaged groups, including the elderly. Reforms to allow accessible living spaces and elder cottages (for elderly parents to move close to adult children for care) promote aging in place and can reduce the necessity for nursing home care (Kochtitzky, Freeland, & Yen, 2011).

Adopting a number of residential land use changes can mitigate adverse environmental consequences at a regional scale such as surface heat islands by up to 40% (Stone & Norman, 2006). Other environmentally favorable land–use changes include the following:

1. reducing average lawn sizes by at least 25%, allowing for more compact development and less impervious infrastructure such as roads,
2. minimizing impervious surfaces by building multi-story buildings to minimize the building footprint, reducing required yard setbacks, and adopting narrow lot frontages to reduce driveway length, and
3. plant shade trees. These actions, in combination with green infrastructure such as highly reflective driveway materials or driveway runners (leaving middle sections unpaved), can reduce impervious surface cover on lots by up to 30%, without requiring any changes to house size or design (ibid).

Strategies to protect source water from contamination associated with residential development include providing designated green space and reducing impervious cover (Source Water Collaborative, 2009a). Over use of resources can be discouraged by setting water and septic rates consistent with the actually cost of water and sewage treatment to state and federal standards. That is, the cost of clean, safe drinking water and waste disposal will be passed on to the consumer.

Among a series of community actions, land use regulations and incentives can be tools for delineating wellhead protection zones, riparian buffers, nitrate loading regulations and storm water management ordinances (Source Water Collaborative, 2009b). Smart growth and brownfields redevelopment can be used to encourage compact development patterns in areas where impacts to source waters will be minimized. The section on Neighborhood Scale Synthesis includes discussion of neotraditional development, transit-oriented development, clustering, and other conservation measures.

3.3.2 Commercial

Commercial land encompasses a wide variety of uses from retail and office buildings to manufacturing, lodging, golf courses, cinemas, and ski resorts. In addition, these uses take many forms, from multistory office buildings, to factories, big box stores or even open recreational areas. Consequently, standard impacts and practices for development are difficult to summarize. Nonetheless, we present some of the key impacts, issues, and considerations regarding commercial land use.

Commercial construction impacts

Construction of new commercial developments carries the same impacts to the environment as residential and civic construction projects. These include deforestation, soil disturbance, increasing impervious surfaces, loss of habitat for native flora and fauna, and changes to river and stream morphology. Adding commercial uses through infill developments or by adding density to existing areas can prevent land conversion from natural to human uses. In addition to the standard impacts of new development, specific commercial uses may have added impacts. For example, ski slope development may require snow-making, machine grading, and other processes beyond the standard impacts. These processes can in turn increase sediment loads, destroy migration pathways, promote soils erosions, increase water temperatures and alter the stream flow and stability of stream banks (David, Bledsoe, Merritt, & Wohl, 2009).

Commercial energy consumption

Commercial land uses consume a significant portion of the energy in a city, about on par with residential consumption. A study based in Toronto on 1990 data found that commercial buildings accounted for 30% of all GHG emissions, compared to 31% for residential buildings and 9% for industrial ones (VandeWeghe & Kennedy, 2007). A model based on Australian cities estimated that 14% of all water related energy usage in a city is used by the commercial sector, compared to 40% by the residential sector (Kenway, et al., 2011). Since estimates can vary by location, technology, and practice these numbers are only rough estimates that provide a starting point for further comparison and verification.

Physical activity and commercial land uses

The presence of commercial physical activity centers, such as physical fitness facilities and YMCAs, is associated with higher levels of physical activity and lower BMI among youth who live nearby (Slater, et al., 2010). Vigorous physical exercise increased by 6.5% and sports participation increased by 8% among youth aged 4 to 16 years of age in neighborhoods with access to physical activity facilities in neighborhoods without confounding physical disorders such homeless persons, dilapidated buildings, or security barriers (ibid). However the commercial use need not be a gym to have an impact.

Most retail and employment centers attract walking and biking trips and are therefore measured as positive elements on most walkability scales (Adams et al., 2009). The presence of commercial land use in a neighborhood is positively associated with bicycling for transportation (Winters, Brauer, Setton, & Teschke, 2010). In downtown areas, evidence suggests that the proximity and density of commercial land use fosters greater use of urban greenways (Coutts, 2009); however, conflicting results also exist. Commercial development appears to increase use of parks and greenways for walking; however busy, difficult to cross streets and large parking lots discourage walking (Kaczynski, et al., 2010). Other studies have elaborated on the impacts of the commercial design noting that the presence of commercial uses can inhibit social interaction in residential areas. This effect can be overcome by designing commercial properties to create pedestrian friendly commercial areas such as wide sidewalks and street facing stores, *in lieu* of surface parking lots (Wood, et al., 2010).

The trend during the post war years was for less walking access to commercial destinations. In a study of five U.S. cities, pedestrian access to commercial uses from home declined rapidly between the 1940s and the 1970s (Knaap, et al., 2007). However, more recently, some cities have begun reversing this trend. In particular, Maricopa County, AZ and Portland, OR, have both increased the percent of homes within ¼ of a mile to commercial uses, though still not to the portion in the 1940s and 50s (ibid).

Economic development through commercial land uses

Communities may be motivated to zone for new commercial development in an effort to increase local job opportunities and generate tax revenues. There is debate over the effectiveness of this strategy.

Several studies indicate that commercial infill development is more effective for economic development than zoning new areas (AKRF Inc, 2011; Mattera & LeRoy, 2003). As a case in point, a fiscal study of Queen Anne's County, MD, emphasizes that increasing the land area zoned as commercial use is not necessarily the most effective way to increase revenue from commercial areas. To the contrary, the authors asserted that the county would better serve the community through infill and occupying vacant buildings (AKRF Inc, 2011). The rationale was that dispersed commercial development has the potential to undermine existing commercial zones. Furthermore, costs rise disproportionately to deliver services to dispersed areas.

The American Farmland Trust estimates that the cost of servicing commercial and industrial uses ranges from $0.04 to $1.04 per dollar spent to each dollar of revenue gained. Moreover, these low returns on investment are subject to unpredictable variables such as the density, distribution, time of year, and opportunities for economies of scale in the community (ibid). Denser commercial areas tend to have service costs at the lower end of the range. Further advantage of the infill approach is attributed to avoiding conversion of dwindling agricultural land and open space to commercial purpose.

In addition to costing a city less, commercial buildings in denser, mixed-use areas may stimulate higher property values and therefore generate more tax revenue (Smart Growth, International City/County Management, & United States. Environmental Protection, 2002). Commercial property values are also increased by proximity to rail stations (R. Cervero, Duncan, & Trb, 2002).

Quantitative relations for commercial uses

- 14% of all water related energy usage in a city is used by the commercial sector (Kenway et al, 2011)
- Commercial buildings account for about 30% of all GHG emissions (VandeWeghe & Kennedy, 2007) and 14% of all water related energy usage (Kenway et al, 2011).
- The cost of servicing commercial and industrial uses ranges from $0.04 to $1.04 per dollar spent to each dollar of revenue gained. These low returns on investment are subject to unpredictable variables such as the density, distribution, time of year, and the opportunity for economies of scale in the community (AKRF Inc, 2011).
- Best practices and unintended consequences

While commercial uses are diverse, mixing commercial uses with residential and civic uses may be a best practice for return on investment. A mix of uses has been shown to increase retail sales and retail visibility. Mixed use centers have the potential to reduce individual commute times by increasing the jobs-to-housing balance, thereby promoting both walking and use of public transit. From the perspective of local governments, dense mixed-use properties generate significantly more property tax revenue than single-use commercial centers and revenues exceed the cost of providing infrastructure service.

Box 17. EPA Product Highlight

A collection of 15 papers on disproportionate health risks has been published by SHC Task 2.2.3.5 in a supplemental issue of American Journal of Public Health. The supplemental issue resulted from an EPA sponsored symposium in 2010 on factors leading to disproportionate health risks. Some of the articles most relevant to land use address the health effects and disproportionate exposure to noxious land uses and health impact assessments as a process to explicitly consider equity in community decision-making. Several of these papers have been cited throughout this land use synthesis paper.

http://ajph.aphapublications.org/toc/ajph/101/S1

3.3.3 Industrial

The protection of communities from potentially harmful releases of industrial chemicals and other pollutants to air, water, and soil is generally assured through state compliance and enforcement of the federal regulations (see Appendix A). Thus, impacts of industrial land use are generally not a community issue.

Nonetheless, there are practices recommended for communities to address potential concerns. One is "performance zoning" also known as "effects-based planning," to incorporates performance standards into zoning laws and ordinances. Another practice is that of *"community health risk assessments,"* which can be required as part of the permitting approval process for new construction.

Box 18. Industrial Ecosystem Toolkit is being developed by Ohio State University through a grant from the EPA to help industries reduce solid waste through collaborative industrial networks.

http://www.resilience.osu.edu/CFR-site/eco-flow.htm

The linking of GIS-based simulations to community health risk management has also been promoted (Willis & Keller, 2007).

Disproportionate health effects

There is evidence of public health impacts due to toxic air emissions. A study based in the Los Angeles air basin found that, assuming a lifetime of exposure, the air toxics in the area would result in 1400 excess cancer cases per million residents(South Coast Air Quality Management, 2000). Birth defects and other adverse health outcomes have been associated with residential proximity to hazardous wastes sites, industrial sites, cropland with pesticide applications, highly trafficked roads, nuclear power plants, and gas stations or repair shops. In particular, these industrial uses have been associated with increased risk of oral clefts (J. D. Brender et al., 2006) perinatal mortality, neural tube defects, congenital anomalies, and childhood cancers(Jean D. Brender, Maantay, & Chakraborty, 2011).

This public health burden from proximity to industrial plants disproportionately affects the poor (socioeconomically disadvantaged) and minorities, who are more likely to reside near industrial facilities. Many studies have identified vulnerable demographic groups who are more likely to be clustered near hazardous land uses(Abel & White, 2011; Maantay, 2001). One study in Seattle comparing the Toxics Release Inventory (TRI) sites to low socioeconomic populations and gentrifying areas found vulnerable populations and toxic release sites converged in the same locations (Abel & White, 2011). In addition, although 11 new toxic release facilities opened during the study period, none of them opened in gentrifying areas.

Proximity increases the probability that individuals more experience adverse health outcomes; however, proximity and exposure do not always align (Jean D. Brender, et al., 2011; Chakraborty, Maantay, & Brender, 2011). In addition, sometimes effects are only seen in certain vulnerable populations. Additional research could help to delineate spatial components and exposure thresholds for different populations and contaminants associated with industrial land uses. Such information could help guide city planners to making zoning and siting decisions to minimize health effects from the high-risk land uses cited above. For example, establishing a buffer zone around industrial parks and other noxious land uses may improve community health.

Finally, disproportionate geographic impacts on health are persistent. Jason Corburn has emphasized the growing recognition of the primary importance of “place” as a driver of public health and human well-being. His concept of “place” is meant to encompass not only the built environment, but the social one as well (Corburn, 2013). For example, improvements in healthcare services may not be able to effect lasting health improvements if residents return to the place where exposure occurred and continues to occur.

Brownfield redevelopment

Brownfield redevelopment of abandoned industrial sites is potentially an economical way for communities to convert abandoned industrial land into community assets. Cleanup is sometimes required.

Barriers to redevelopment can arise because if residual contamination, unknown remedial costs, unpaid property taxes, or the stigma of previous contamination. These concerns can promote urban sprawl if development of previously undeveloped parcels is seen as less expensive and more expedient.

Federal and state brownfields programs are designed to promote reclamation and repurposing of previously used land to commercial use.

Examples include former industrial plants reused for highway interchanges, park and ride lots for commuter train service, and for mixed-use development (Agency, 1999; De Sousa, 2013; US Environmental Protection Agency, 2012a).

Gas stations and adjacent contaminated properties have been reclaimed and redeveloped for a variety of purposes, including the following: A biofuels station (US Environmental Protection Agency, 2007a), community gathering spaces, college classrooms, and housing (US Environmental Protection Agency, 2008a, 2008b, 2008c, 2012a), a community food bank (US Environmental Protection Agency, 2008c), a community welcome center (US Environmental Protection Agency, 2002b), part of a federal reserve bank (US Environmental Protection Agency, 2007b), an events center in Reno, Nevada (US Environmental Protection Agency, 2006b), an organic farm (US Environmental Protection Agency, 2003), and many others.

Brownfields redevelopment facilitates the reintroduction into commerce of formerly contaminated sites. These sites provide an opportunity for in-fill development that prevents sprawl, fosters sustainable development using smart growth principles, and can support business development and job creation.

3.3.4 Agriculture

Agricultural production accounts for nearly 51 percent of the U.S. land base: conversion of agricultural land to other purposes has the potential to impact food production and the economy. Other valued resources can also be jeopardized--wildlife habitats, bucolic landscapes, open space, and the perpetuation of farm culture as a way of life and as a national heritage (ERS, 2012b).

Urban expansion is consuming former agricultural land at an accelerating rate (American Farmland Trust, 2007). In the Midwest, total annual crop production is expected to drop by 8% to 16% by 2030 due to urban expansion and loss of arable land (A. Schneider, et al., 2012). Agricultural land use impacts the environment, human wellbeing, and the economy in many ways, both beneficial and not.

Crop production helps ensure food security and rural livelihoods, sequesters carbon, and provides some wildlife habitat and aesthetic appeal, and is a significant component of national exports. It also reduces water quality and quantity, can contribute to invasive species, and in some cases, may perpetuate income inequality.

Crop production and animal husbandry are both fundamental aspects of agriculture. The following section addresses crop production, which have different considerations than those of confined animal feeding operations (CAFOs), which generate concerns for odors, sanitation, and environmental justice (Mirabelli, Wing, Marshall, & Wilcosky, 2006).

Agriculture, water quality, and hydrology

Agricultural practices are inherently water intensive. Fertilization and tillage affect surface and subsurface hydrology and water quality. Runoff from agricultural uses contributes to high levels of phosphorous, nitrogen, and sediment in receiving waters. Excess nutrient loading is a key cause of degradation to fresh water habitat and water quality (Havens & Gawlik, 2005; Hogan, et al., 2012; Mueller-Warrant et al., 2012; Wardrop et al., 2011).

Over the past century, agricultural drainage solutions have caused cumulative changes to the surrounding landscape including broad declines in sensitive aquatic species (Blann, et al., 2009).

Mitigating practices for excess nutrients are evident. Over the past two decades, farm practices have moved to achieve lower application rates and reduce reliance on pesticides and fertilizers. For example, from 2004 to 2010, fertilizer consumption fell from 23 million short tons to 21 million short tons (Osteen & Jessica Gottlieb, 2012). Irrigation efficiency is improving (ibid).

Despite these favorable changes, the water quality impacts of agriculture remain an important environmental challenge, in part because of the inherent difficulty of regulating and managing non-point source occurring through runoff.

Beyond the potential for adverse effects of agricultural runoff on aquatic ecosystems, agriculture is also associated with changes to diversity of plant species beyond the monoculture of crop species. A higher incidence of nonnative plant species is characteristic of agricultural land (Decker, et al., 2012).

Agriculture and natural resources

Agricultural land use has been linked to depletion of water resources and consumption of energy reserves (Lobao & Stofferahn, 2008) as well as increasing carbon emissions as a result of deforestation (Younger, Morrow-Almeida, Vindigni, & Dannenberg, 2008). In 2005, agricultural land use contributed 10% to 12% of anthropogenic carbon emissions worldwide; 80% of these are from livestock production (ibid).

The extent to which large-scale, industrialized farming consumes or saves energy compared to traditional family farms has been studied (Lobao & Stofferahn, 2008) but is probably a moot point when considering the need to increase food supply to meeting anticipated increases in for food supply.

Agricultural services

Agricultural land use has environmental benefits as well, particularly when compared to more intensive uses. Farmland provides ecosystem services in addition to food. Though agriculture stores less carbon than natural vegetation, it does provide some carbon sequestration, and this service can be augmented though practices that increase soil organic carbon (Morgan et al., 2010). The Ecosystem Portfolio Model shows that converting agriculture to urban, industrial, and extractive uses lowers metrics of ecological value overall (Hogan, et al., 2012).

Food security

Food security is an essential element of human wellbeing, and one that depends on long-term land use planning to ensure adequate fertile land, water quantity, and water quality. Communities struggle with the best ways to achieve this goal while minimizing undesirable tradeoffs.

Agricultural land is valued aesthetically for its rural countryside charm as well as for its role in slowing growth and reducing development (Heimlich & Anderson, 2001). However since the most productive agricultural lands are also those most desired for suburban development, competition can occur between the goals of rural charm, food production, rural livelihoods, economic development, population growth, and conservation, all of which have multiple intersecting tradeoffs. Several tools are that are designed to help communities weigh alternative scenarios and evaluate consequences of various choices.

Farm employment

Agriculture, forestry, and mining remain important sectors in some rural areas; however, service and retail industries have accounted for most job growth in rural America over the past few decades. During the Depression of the 1930s, the rural and farm economies in the United States were largely synonymous, as those rural residents not working on a farm either provided direct support services to those on the farm or ranch or worked for businesses that provided services to the farm sector.

As of 2007, 5.9 percent (1.5 million) of rural (non-metropolitan) workers were employed in agriculture, with a somewhat smaller share of workers employed in closely related industries, such as agricultural services, processing, marketing, and inputs (ERS, 2009). The current rural economy is far more complicated. Farming now ranks behind manufacturing, construction, retail trade, health services, and Government as source of rural jobs (based on data from the U.S. Department of Commerce, Bureau of Economic Analysis). In terms of economic dependence, farming is second only to manufacturing as the dominant activity in industry-dependent counties (ERS, 2012a).

The agriculture industry remains a primary economic driver in some rural areas. In North Carolina, it is estimated to add $32.1 billion in value to the economy and employs 120,000 people (The Trust for Public Land, 2011). Agriculture may become increasingly important as ethanol production supplies more energy resources as well. Agricultural land may become a large source of biomass for biofuel. A report by the California Energy Commission estimated that about 30% of material for biofuels in the state could come from agriculture (California Energy Commission, 2005).

Industrial farming and socio-economic well-being

Farming is not always a force for economic prosperity, and the nature of the impact may depend upon the type and scale of the enterprise. A comprehensive review of the literature on the impacts of industrialized farming (defined by both the scale and type of organization) between 1930 and 2007 found that in 75% of the 51 studies, the impacts on socio-economic well-being, social fabric, and the environment were negative (Lobao & Stofferahn, 2008).The remaining 22% of studies reported mixed impacts or benign effects.

Large-scale industrialized farming was sometimes associated with a positive impact on community income. In the majority of studies, however, industrial farming was associated with lower incomes for selected populations, greater income inequality, greater poverty, or higher overall unemployment rates (ibid). Industrial farming has also been linked to more indirect impacts on the social fabric including a decline in population size, social disruption including an increase in crime rates, lower civic participation, less democratic decision making, and reduced or lower quality public services (ibid).

Aesthetic impacts of CAFOs

Concentrated animal feeding operations (CAFOs) also have impacts that are of interest to land use decision makers in particular. First, the operations have negative aesthetic impacts, such as noxious smells, beyond the health and environmental impacts, which impact adjacent properties. Second, these intensive agricultural operations tend to be sited in low-income and minority communities, potentially creating and environmental justice situation of disproportionate exposures of vulnerable populations. In a study of North Carolina middle schools, schools with greater than 47% of students receiving reduced-price lunches, a common proxy for poverty, were located much closer to swine CAFOs. These high-poverty schools were located at a mean of 4.9 miles from a CAFO, while lower poverty schools were a mean of 10.8 miles (Mirabelli, et al., 2006).

CAFOs and jobs, property values, income, and inequality

CAFOs have emerged as an efficient and cost effective way to produce large amounts of livestock for food production. CAFOs also provide jobs and income to local communities. From a macroeconomic perspective; however, some of the positive effects on employment may be offset by the negative effects of CAFOS on surrounding property values. Home values have been shown to be reduced by 3 to 10% by the presence of CAFOs at a distance of 1 mile (Milla, Thomas, & Ansine, 2005).

In a meta-analysis of studies on the community impacts of industrial farming 82% percent of studies reviewed showed detrimental impacts relative to smaller farms and family owned farms reflected "deterioration of neighborly relations," decreased retail trade, less diverse retail, and less civic participation (Lobao & Stofferahn, 2008).

A Workgroup on Community and Socioeconomic Issues sponsored by the University of Iowa and the NIEHS reviewed the impacts of concentrated animal feeding operations (CAFOs) on the health and sustainability of agricultural communities. The workgroup recommended several policy changes including "a more stringent process for issuing permits for CAFOs, limiting animal density per watershed, enhancing local control, and mandating environmental impact statements (ibid)." Tools to identify locations for CAFOs that minimize impacts on sensitive groups would be helpful here.

Quantitative relations for agricultural uses

- Agricultural land use accounts for 10 to 12% of anthropogenic carbon emissions worldwide (as of 2005); 80% of these emissions are from livestock production (Younger et al., 2008)
- Industrial farming is associated with lower incomes for select populations, higher income inequality, greater poverty, higher unemployment rates, lower civic participation, and less democratic political decision making were evident according to a literature review of 51 studies (Lobao & Stofferahn, 2008)

- Agriculture could provide about 30% of feedstock for biofuels (California Energy Commission, 2005) Home values may be reduced from 3 to 10% by the presence of CAFOs at a distance of 1 mile (Milla, et al., 2005)
- CAFOs are more likely to be located close to schools serving high poverty communities (Mirabelli, et al., 2006).

Best Practices and unintended consequences

While some farming practices (e.g., excess fertilization and over use of pesticides) can degrade natural resources, USDA conservation programs offer farmers a range of options for assistance with conservation that can contribute to land preservation and land retirement programs and for land in production.

In rural agricultural communities, planning practice has been to cluster residential and commercial areas so as to preserve agricultural land, minimize development impacts on agricultural land and open space, and reduce exposure to pesticides (California Governor's Office of Planning and Research, 2010). A guide developed for the Rhode Island Department of Environmental Management provides concrete strategies for communities to incentivize landowners to maintain working farms and forests (Horsley Witten Group Inc, 2012). The report identifies case studies, supporting zoning and regulations, and specific performance standards.

Other successful practices include the transfer or purchase of development rights and to compensate owners to forego offers of purchase (Nelson, 2012).

Conservation practices sometimes have unintended consequences for residents within the region. Evidence suggests that property values are higher in areas with more agricultural land under conservation protection; however, it is not clear which specific elements drive this response. Research is necessary to determine whether and when agricultural conservation policies will raise property values to sufficiently to have the unwanted effect of displacing low socio-economic residents (Poor & Brule, 2007).

Box 19. EPA Product Highlight

A report synthesizing policy and management tools for reducing nutrients was produced by SHC task 3.3.1.2. The researchers concluded that most successful approaches come from flexible command and control regulation of point sources, and that current efforts are hampered largely by the challenges of regulating non-point source pollution, such as agricultural runoff and atmospheric releases. Successful locally applicable approaches that were highlighted include working with farmers to implement BMPs.

3.3.5 Parkland and Open Space

Preserved natural areas make up a significant proportion of our country's land and impact sustainability in a

Box 20.
EPA Product Highlight

A peer reviewed report of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes was produced by SHC Task 2.1.4.4. The report reviews the evidence for ecosystem services produced by the coastal wetlands of the Great Lakes including carbon sequestration, sport and commercial fish, retaining sediments and wild rice production. Their research has highlighted a need we also find: to identify quantitative relationships between land use decisions and the delivery of ecosystem services.

variety of ways. According to the United Nations Environment Programme, federally protected areas comprise about 27% of the land area in the United States. In addition, many states and local jurisdictions maintain preserved natural areas. Parkland provides ecosystem services, provides an opportunity for physical activity, and generates revenue through ecotourism. Note that in this section we discuss large undeveloped natural areas, including preserved land, state and national parks, and peri-urban forests and open space. Community parks are discussed under the section titled “Access to parks and greenspace.”

Ecosystem services of Parkland

Preserved natural areas serve a critical role in providing ecosystem services including groundwater purification, good air quality, storm and flood control, biodiversity, and habitat connectivity.

Forested land near cities improves the air quality of nearby urban areas by filtering common air pollutants. A study based around Mexico City estimated that a 40,000 hectare peri-urban forested park reduced the city’s air concentrations of pollutants by approximately 0.02% for CO, 1% for ozone, and 2% for PM10 (Baumgardner, Varela, Escobedo, Chacalo, & Ochoa, 2012). The term peri-urban refers to natural areas immediately adjacent to a developed area, typically outside the suburban zone (Tzoulas et al., 2007)

Peri-urban forests not only benefit air quality, but can also help ease the urban heat island effect. This is because forests increase humidity of the air due to evapotranspiration. In extreme cases of deforestation, the loss of this service can cause aridity and desertification. However, even at moderate scales, forest evapotranspiration provides a valuable service, cooling the air temperature. In addition, urban tree cover provides shade, further cooling the ambient air temperature. For this reason, trees in and near urban environments can reduce the magnitude of the relief from the urban heat island effect (Manning, 2008).

Biotic integrity of Parkland

Minimum thresholds of forest cover to maintain biotic integrity and good ecological conditions have tentatively been established using bird species data as an indicator. In developed areas, national, state, and local parkland and preserves can provide the threshold levels of forest cover necessary. Excellent biotic integrity is maintained with at least 82% forest cover. Poor biotic integrity begins at roughly 56% agricultural or herbaceous cover and at roughly 39% residential or commercial cover (J. L. O'Connell, Johnson, Smith, McMurry, & Haukos, 2012). Established thresholds such as these may be valuable information for modelers as well as for land use planners to set land cover goals for the region. The thresholds can also help determine which areas may be in borderline condition and could be saved from poor condition or achieve excellent ecological condition with relatively small investment or change in practice.

Physical Activity in Parkland

In addition to the ecosystem services that parks provide, they also provide an opportunity for physical activity and may be able to encourage it with marketing. A study of federal parks in California found that they provide physical activity opportunities for diverse groups (Chavez, Winter, & Absher, 2008). In another study of US National Parks, five of the seven national parks considered showed an increase in physical activity due to intervention activities, which included print and electronic material that encouraged use of the parks (Hoehner, et al., 2010).

The accessibility of state and national parks may vary by groups and be less accessible to low socioeconomic groups in particular. One study found that "my financial situation" was the second most commonly cited constraint to visiting undeveloped natural areas (UNAs) (39%) after "my family and friends do not visit UNAs" at 42% (Chavez, et al., 2008).

Ecotourism. Although large protected parks and open space are primarily preserved to protect biodiversity, habitat, and ecosystem goods and services, they can also provide recreation and subsequent economic benefits to a community. Mulongoy and Chape (2004) estimate that ecotourism in Canada and the United States has a value, respectively, of $237 and $370 billion in 1996 (Chavez et al., 2008).

Quantitative relations for parkland

- 82% forest cover maintains excellent to good biotic integrity for bird communities in the central Appalachians (T. J. O'Connell, Jackson, & Brooks, 2000).
- Poor biotic integrity begins at roughly 56% agricultural or herbaceous cover and at roughly 39% residential or commercial cover (ibid).
- A forested area of about 40,000 hectares near an urban center reduced the annual concentrations of CO by 0.02%, of ozone (O_3) by 1%, and of PM_{10} by 2% in the city (Baumgardner, et al., 2012)
- United States forests offset approximately 6% of U.S. CO_2 emissions (Turner & Koerper, 1995).

Best Practices and unintended consequences

Land banking is one of the most common practices used to preserve land for future community needs. As the many benefits of parkland and large signature city parks are increasingly recognized, it has become an effective way to preserve land for open space at an affordable cost to a community.

Land banking started in the 1970s to manage and repurpose vacant or abandoned land due to deindustrialization and suburbanization, and turn it to make a profit once property values returned. However, the method has also been adopted as a way to preserve land for public use against development and rising property values. Land banks, often managed by a nonprofit or municipality, purchase land at current market rates. This approach is particularly useful in areas that are expected to grow quickly, because land prices can rapidly become too high for cities to purchase parkland. In addition to providing public goods, this preserved land will increase nearby property values and tax revenues for the community.

Because the success of land banking depends on timing and the availability of large parcels of land, an alternative approach is to conserve land in smaller pieces while maintaining connectivity crucial to home ranges and habitat of flora and fauna.

Growth controls or zoning restrictions are sometimes used in an attempt to slow the loss of parkland adjacent to urbanized areas. However this may not always be effective. At least in a study of Southern Indiana, the existence of county level zoning did not affect the conversion of forest to urban uses (York and Munroe, 2010). This study did not isolate the impact of the more restrictive growth controls, like urban growth boundaries, however, so it is unclear to what extent these may be more successful.

The Trust for Public Land outlines a best practice methodology for periurban forest management that they term the Community Forest Model which aims to preserve a sustainable, permanent forest, while also ensuring community access to monetary and nonmonetary forest services such as timber, recreation, and avoided costs of water treatment (Lyman, Evans, & Mytar, 2011).

The ability to track and model land cover change and fragmentation is improving, opening the possibility for new, more insightful decision-support tools. The University of Connecticut has developed models that use satellite based land cover data to quantify and describe forest and open space fragmentation, in addition to urban growth pattern and change (Civco, Hurd, Wilson, Arnold, & Prisloe, 2002). With these advances, conservation planning software has been developed to identify and prioritize preservation corridors that can provide the most connectivity at the least cost (Carroll, McRae, & Brookes, 2012; La Greca, La Rosa, Martinico, & Privitera, 2011). While this threshold has been established for natural cover to maintain biotic integrity of forests, less is known for non-forested biomes. Validation of software is also critical to enhance the utility of such software.

3.3.6 Roads

Roads, as a land use, have profound impacts on the landscape. Coffin (2007) estimates that 83% of the land area in the continental United States is within about 1 km of a roadway. When considering the full sustainability impacts of roadways as a land use, one must consider the impact of increasing the amount of land dedicated to this use, the impact of what route a road follows, and the impacts of different roadway design and construction elements. More on these topics may be found in the forthcoming SHC Theme 4 synthesis paper on sustainable transportation (SHC 4.1.3), currently in preparation.

Habitat destruction and fragmentation from roads

Roads occupy a significant amount of land, and directly reduce and fragment habitat (Coffin, 2007). In addition to directly causing deforestation, road development spurs further destruction of habitat by enabling and promoting new development. Roads impact biodiversity and wildlife through fragmentation effects as well, including hindering migration, dividing territories, separating breeding populations, and road kill (Haskell, 2000). After impervious surfaces, roads, and the land fragmentation they cause, are one of the most important stressors on aquatic ecosystems (M. Alberti, et al., 2007). Roads not only add to impervious surface cover, but also increase runoff and sediment deposition to streams and often lead to channel alteration of waterways.

Roads impact habitats and ranges for large mammals as well. In Florida, the primary source of all mortality for large endangered vertebrates, such as panthers, black bears, deer, and crocodiles, is motor vehicles (Coffin, 2007). Small mammals, insects, and “generalist” species, roads, such as coyotes and foxes, can spread swiftly using roadway corridors. In some cases, these corridors of migration can facilitate the spread of invasive species (ibid).

On top of the direct site-specific ecological impacts roads have, road networks have cumulative region-wide impacts on the landscape and ecosystems. These effects are not yet well understood and research to understand the differential ecosystem-level effects of alternative road networks would be valuable (ibid).

Finally, there exists a tradeoff between well connected road networks, which in concert with small blocks and a mix of uses, has been shown to increase walking and reduce driving, and having a well connected landscape, which is important for many species survival.

Road construction and soil impacts

Conversion of natural land to developed land is inherently destructive to soils. Soils absorb water, which can prevent flooding; provide habitat to support plant and animal life, and contribute to vital ecological process of energy flow and nutrient cycling. Clear cutting land to make room for buildings; paving land to create roads, streets, sidewalks, plazas; even the compaction of earth from heavy equipment moving across unpaved land or, long-term foot traffic all serve to diminish these inherent ecological functions of soil. Soil compaction alone is highly detrimental to soil fertility. Compacted soils do not retain water, nor air pockets essential for terrestrial plant roots to breathe and grow. When soil is compacted, water no longer percolates through the soil to enable aquifer recharge or removal or degradation of contaminants. Hydrologic processes can be entirely disrupted when soils are disturbed, compacted or paved over.

Impervious surfaces from roads

Numerous studies have concluded that high levels of impervious surface area are detrimental to the health of watersheds and the ecosystem services that they provide (T. R. Schueler, 1994). Many elements of human settlement create impervious surfaces, however, building footprints are often not the primary source. Roads, parking lots, driveways, sidewalks, and other transportation-related land uses are the single largest contributors to the overall impervious surfaces. The leading role of transportation land uses in producing impervious surfaces is confirmed by the two studies showing that roads, parking lots, and driveways account for 60 to 70% of overall imperviousness in metropolitan watersheds (City of Olympia, 1995; Goetz et al., 2004). Transportation-related land uses represent an especially high percentage of overall impervious surface area in suburban and rural regions. In these locations, longer roads and longer driveways are needed to connect buildings that are spaced farther apart and larger parking lots are needed to serve a more auto-dependent population (T. R. Schueler, 1994).

Roads, like other impervious surfaces, increase stormwater runoff, which contributes to higher peak flow in streams, increases flood vulnerability, and erodes channel banks (Coffin, 2007). In addition, road construction and maintenance introduces a variety of chemical pollutants, such as pesticides, deicing salts, hydrocarbons, heavy metals, and particulates, , all of which are carried by runoff from roads to waterways (Kramer, 2013). For example, runoff from heavily used asphalt parking places had toxic levels of zinc and copper in 97% of samples, and contained detectable levels of motor oil in 89% of samples (Brattebo & Booth, 2003).

Relationship of roads to water infrastructure

The construction and configuration of roads significantly impact the provision of water and wastewater infrastructure. However the best ways to coordinate the provision of roads and the provision of water and wastewater infrastructure in a metropolitan area currently represent a significant research gap. Water and wastewater pipes are typically buried alongside major roadways. The development, and hence the need for new water and wastewater service, often follows in reaction to roads built to serve an area. In fact, the provision of efficient transportation infrastructure is a major driver of urban sprawl (Burchfield, Overman, Puga, & Turner, 2006; R. H. Ewing, 2008), which has a significant influence on the efficiency and sustainability of water and wastewater infrastructure.

Most U.S. urban areas start out with highly centralized water and wastewater systems, which then expand as the urban area expands. As expansion occurs, new components of the system are typically built as extensions of the existing network. Eventually, distributing fresh water across vast distances from a centralized location and moving wastewater across equally vast distances to a centralized collection point becomes both energy inefficient and a physical strain on pipes to handle increased demand. Breaches, seepage, and backflow are the unwanted consequences of infrastructure that develops in this manner.

Near-road air pollution

Though major roadways benefit users in the form of increased accessibility, users often receive a disbenefit in the form of increased exposure to motor-vehicle-generated air pollutants, which are estimated to affect 30-45% of the urban population of the United States who live within several hundred meters of a high volume roadway (Y. Zhou & Levy, 2007). As summarized by Karner, Eisinger, and Niemeier (2010), concentrations of many traffic-generated air pollutants can be highly elevated within the first 100-150 meters of a large roadway, with concentrations above urban background levels as far as 600 meters from the road. As a result, it may be unadvisable to develop certain buildings along transportation routes where either a very large number of people or people who are considered particularly susceptible to the effects of air pollution will be in close proximity to vehicle emissions on a regular basis. However, the complexity of pollutant transport from roadways, especially in urban environments, makes it difficult to identify what distances can be considered “safe” and what road traffic volumes are a concern. In addition, land use planners need to consider the benefits of accessibility and active transport by local residents in addition to the health concerns related to air pollution exposures near roads.

Near-road air pollution includes emissions from the combustion of motor-vehicle fuel, fluids that evaporate from vehicles’ engines, chemicals that result from secondary reactions of vehicle emissions in the atmosphere, and particles released into the air by the friction exerted upon brakes, tires, and roadway surfaces. Amongst the numerous emissions that are found in higher concentrations around heavily-traveled roadways are carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NOx), and such particulate matter components as black carbon (BC) and polycyclic aromatic hydrocarbons (PAHs). Since 1970, U.S. emissions of NOx, PM10, and VOCs per VMT have been reduced dramatically. However, this benefit has been offset by increased rates of driving (Dallmann & Harley, 2010)).

International consensus has emerged that exposure to traffic-generated air pollution near large roads increases risks for a number of adverse health effects, including asthma, cardiovascular disease, adverse birth outcomes, cancer, and premature mortality (HEI Panel on the Health Effects of Traffic-Related Air Pollution, 2010). Most air quality studies on this subject have focused on roads with Average Annual Daily Traffic (AADT) counts of 100,000 or higher, but some health studies have found significant effects for populations near roads with traffic volumes as low as 10,000 AADT, and certain portions of the population are more susceptible to adverse health effects from exposures to air pollution, including children, the elderly, outdoor athletes, and people with existing health conditions (ibid). In addition to building ventilation and road treatments, some land use treatments may reduce near-road air pollution concentrations, including vegetation buffers and physical separation of high traffic roadways from pedestrian routes (Baldauf, et al., 2009).

Noise pollution

After controlling for the effects of near-road air pollution, there is still a correlation between exposure to motor-vehicle traffic noise and the conditions of hypertension and ischemic heart disease (Davies & Kamp, 2012). In a study in western Europe, the World Health Organization concluded that noise pollution from transportation corridors resulted in a substantial loss of disability adjusted life years (DALYs) (World Health Organization, 2011). However, these results were primarily attributed to the noise affecting people's sleep and causing them annoyance, events that have yet to be linked by significant evidence to any specific health condition (Hume, Brink, & Basner, 2012). Noise from major roadways can also affect wildlife, particularly those who use sound for basic functions, such as birds (Coffin, 2007).

Traffic accidents

In spite of significant reductions over the last twenty years, roadway accidents are still one of the leading causes of death and injury in the United States. They are the number-four cause of emergency-room visits for nonfatal injuries, one of the ten leading causes of death for the general population, and the most common cause of death of all for people between the ages of 5 and 24 (Centers for Disease Control and Prevention).

When a community is deciding whether or not to dedicate additional land to roadways, it is prudent to consider the amount of risk of traffic-related injuries and deaths associated with such roadways. However, the number of traffic injuries and fatalities that occur along a jurisdiction's roadways may misrepresent the amount of risk to any given traveler, since it does not account for how many people use the roadway or how much time they spend on it. Arriving at a standardized metric for the risk of being injured or killed in a traffic accident represents a significant research gap. Although traffic-accident injuries and deaths among motor-vehicle occupants are often reported on a per-vehicle-mile-traveled basis, there is less consistency in how the risk of being in a traffic accident is reported for pedestrians and cyclists.

Locations in which the total number of pedestrians and cyclists is higher tend to carry a lower risk of any given pedestrian or cyclist being in a traffic accident, a phenomenon referred to as safety-in-numbers (Jacobsen, 2003). Therefore, it has been suggested that one "best practice" for reducing the risk of injuries and fatalities along roadways is to institute policies and design features that encourage walking and cycling, based on the theory that drivers who see a large number of pedestrians and cyclists using the same transportation corridor will adopt more cautious driving habits than if pedestrians and cyclists were only occasional users of the corridor. However, it is not guaranteed that this is the causal link that produces the safety-in-numbers phenomenon (Bhatia & Wier, 2011). For example, it could be that a particular transportation corridor is first made safer for pedestrians and cyclists, such as through design changes, and that event motivates a greater percentage of people to choose to walk or ride bicycles, in which case the greater number of pedestrians and cyclists would not necessarily be the cause of any additional improvement in safety. Furthermore, if people choose to walk or bicycle for trips that they would otherwise have made by motor vehicle, overall vehicle traffic volume is reduced, an event that is strongly associated with fewer traffic accidents.

Quantifying Economic Impacts of Roads

The easiest economic impacts to express quantitatively are the costs of building and maintaining a roadway. Less easy to express in quantitative economic terms are environmental impacts and societal outcomes, such as increased or decreased destination accessibility and traveler safety (Shadewald, Hallmark, & Souleyrette, 2001). A common indirect economic impact is the attraction of increased development activity to the parcels of land that surround a major roadway, in response to either actual or anticipated increases in accessibility or visibility (Hof, et al., 2012). On the other hand, certain types of development can be discouraged in an area around a roadway on account of such intermediate drivers as near-road air pollution and noise pollution (Hof, et al., 2012; Jha & Kim, 2006). Indirect economic impacts, such as effects on the real-estate market, are often difficult to plan for, as they may take many years to be fully realized (Polzin, 1999; Szeto, Jaber, & O'Mahony, 2010). Furthermore, because indirect economic impacts are not necessarily additive, the risk exists of indirect costs and benefits being double-counted (Hof, et al., 2012).

Quantitative relations for roads

- Transportation-related surfaces appear to constitute about 60-70% of overall imperviousness in metropolitan areas (City of Olympia 1995 and Goetz et al, 2004)..
- A 10% increase in roadway lane-miles is associated with a 5-10% increase in Vehicle Miles Traveled (Sinha, 2003)
- 70% of the variability in private automobile ownership between different areas and 76% of the variability in automobile use between different areas can be explained through correlations with the amount of road length per capita in each area (Sinha, 2003)
- Runoff from asphalt parking spaces had toxic concentrations of copper and zinc in 97% of samples, while less than 14% of samples infiltrated through permeable concrete did (Brattebo & Booth, 2003).
- Runoff from asphalt parking spaces had detectable levels of motor oil in 89% of samples, while no infiltrated water samples did (Brattebo & Booth, 2003).

- For stream insect communities, at least, the threshold of percent total impervious area (PTIA) in the watershed appears to be anywhere between 5% and 25% (Morse, Huryn, & Cronan, 2003). Above the threshold, diversity drops precipitously.

Box 21. Integrated Urban Water Management (IUWM) is an approach that aims to helps communities plan for sustainable water infrastructure. The approach emphasizes the use of decentralized solutions such as rainwater tanks and local wastewater recycling (Burn, Maheeplala, and Sharma, 2012). This approach may be particularly effective for sprawling areas where centralized water management systems are stretched to the point of inefficiency.

Best Practices and unintended consequences

Roads directly impact the landscape, and reduce water quality and vegetation, increase stormwater runoff, and fragment habitats. Indirectly, they influence a host of land use and planning issues including the expansion of sprawl, water system efficiency, travel behavior, air quality, and more. While some of these impacts may be inescapable given the necessity for travel, many impacts can be mitigated through changes to transportation practices, building design, regional planning, and land use.

A compact development pattern has the potential to mitigate many of the direct impacts from roads. Compact development minimizes the amount of roads necessary to serve a given population (T. R. Schueler, 1994). This is turn minimizes the habitat destroyed and fragmented, as well as impervious surface cover. A fundamental challenge to this has been discussed by researchers. A necessary tradeoff exists between provisioning land for roads, to aid mobility, and for non-road uses, particularly in the compact city center. The road segments in the center of an urban area tend to be along a greater number of the routes between travelers' origins and destinations than the road segments in other parts of the urban area. Consequently, these areas are under the most pressure to expand road capacity, and yet there is also a strong motive to dedicate more land in the center of an urban area to non-road uses, necessitating a tradeoff (Medda, Nijkamp, & Rietveld, 2003). Balancing these tradeoffs may require forecasting tools as well as a shift towards less road intensive forms of transportation, such as walking, bicycling, and transit.

4 Relevant Metrics, Indicators, and Indices of Sustainability

4.1 Metrics of development form and pattern

Population and employment density are among the most commonly studied urban form variables. However, researchers are finding that despite their associations with many sustainability outcomes, they alone do not explain variations in many land use impacts (M. Alberti, et al., 2007). Density measures must be taken together with urban form patterns, which appear to have more direct impacts. For example, compactness refers to a development pattern that is contained and contiguous. It requires a degree of density, but refers to more than just that. Some of the literature on compactness refers to "The compact city," and assigns to it many of the characteristics associated with holistic smart growth: high densities, land use mix, fine grain of land uses, contained urban development, multimodal transportation, high street connectivity, and more (Neuman, 2005). However this formulation exists mainly as theory. In studies, compactness is typically measured either through simple density or through a sprawl index.

4.1.1 Measuring sprawl and compactness

How to best define and measure sprawl, urban growth, and compactness is still under debate (Kumar, et al., 2007; E. H. Wilson, et al., 2003; Zhang & Wang, 2006; G. Zhou & He, 2007). Development of a standardized, universally accepted definition of sprawl could speed development of useful metrics for sprawl (E. H. Wilson, et al., 2003; Wolman et al., 2005).There have been numerous attempts to define its meaning. Sprawl is broadly defined as the use of land to create low density development that occurs in the transition zone from rural to urban communities. More specifically, sprawl has been described (Russ Lopez & Hynes, 2003) as containing one or more of the following elements;

- low-density development;
- separation of land uses;
- leapfrog development;
- strip retail development;
- automobile-dependent development;
- development at the periphery of an urban area at the expense of its core;
- employment decentralization;
- loss of peri-urban, rural agriculture, and open space;
- fragmented governmental responsibility and oversight

This suggests that the processes creating sprawl are varied and that there can be many varieties of sprawl. Ewing et al. (2003) identified sprawl as the process in which the spread of development across the landscape far outpaces population growth. They recognized that the landscape sprawl creates has four dimensions: a population that is widely dispersed in low density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centers, such as downtowns and town centers. They are able to generate a Sprawl Index which can quantify the degree of Sprawl for any given area using data for 22 specific measures within these 4 dimensions. Most of the other features usually associated with sprawl—the lack of transportation choices, relative uniformity of housing options or the difficulty of walking—are a result of these conditions.

One measureable consequence of sprawl is the expansion of land consumed per capita.

Yet sprawl is more than a lack of density (Joshu, et al., 2008). Urban sprawl is also a function of how density is distributed across a metropolitan area. Instead of a single definition, some promote four common dimensions of the landscape that sprawl creates: “a population that is widely dispersed in low density development; rigidly separated homes, shops, and workplaces; a network of roads marked by huge blocks and poor access; and a lack of well-defined, thriving activity centers, such as downtowns and town centers (R. Ewing, R. Pendall, et al., 2003).” Given the difficulty in defining and measuring sprawl, others reject the dichotomy between urban and sprawling land use. Instead they promote the idea of four distinct land use patterns:

Box 22. EPA Product Highlight

Common sustainability metrics and indicators are catalogued in a report that ranks the 50 most populous cities in US based upon these metrics (SHC Task 2.2.1.1). They conclude that the inclusion or exclusion of sustainability metrics has a large impact on the rank ordering of cities, over and above the health and environmental rankings alone.

This product may be a useful resource not only for researchers and sustainability index developers, but also for community decision makers to make the case that tracking sustainability will improve local outcomes.

1. “deconcentrated, dense areas: intensively and continuously developed but without major clusters;
2. “leapfrog areas: highly concentrated pockets amid generally low density, discontinuous development;
3. “compact, core-dominant areas: development with high proximity to the central nucleus, but only moderate density and continuity;

4. "dispersed areas: development extending far from the core without notable concentrations or nuclei (Cutsinger & Galster, 2006)."

Methods to measure sprawl typically include satellite land cover data to classify land into various degrees of urbanization, and 2) growth patterns, including infill, expansion, isolated, linear branch, and clustered branch (E. H. Wilson, et al., 2003). Modifications, including the addition of road density and additional sprawl indicators, have been used to improve this approach (R. Ewing, R. Pendall, et al., 2003; Kumar, et al., 2007). Recently, urban ecologists have emphasized the need to incorporate a temporal perspective in measuring the degree of urbanization, particularly in modern sprawling cities where developed areas often have a history of agricultural use and varying degrees of remnant vegetation over time (Ramalho & Hobbs, 2012). This history of disturbance informs the current vegetation condition, species condition, a biodiversity response (ibid).

4.1.2 Metrics of urban form

As discussed above, recent literature has been moving away from using neighborhood scale density as a metric of good urban development, towards more form-based measures such as street connectivity and mixed-uses. That is for very good reason. Density is a very imprecise way to approximate urban form at neighborhood level. Not only does it not capture important variations in urban form such as a mix of uses, street intersection density, sidewalks, setbacks, and more, but it also is easily distorted. For example, lower densities in city centers can arise from abandonment and high vacancy.

How land use characteristics are measured significantly impacts the results of studies, which can confuse the effort to determine the impact of land use characteristics on human well being. This is particularly evident in the measurement of mixed-uses. First of all, the geographic scale is important. Some studies analyze a mix of uses based political boundaries, such as the census tract. This method obscures variations in size, and may attribute a high land use mix to a distance that couldn't be covered by a walker. More reliable studies perform an analysis at a smaller scale.

Second, the particular mix of land uses included affects the outcome (H. E. Christian, et al., 2011). The land uses most relevant to walking appear to be residential, commercial, and institutional. Including industrial, agricultural, or parkland in the measure may give a high measure of mixed-use to an area that is of little interest to potential walkers.

Third, for many outcomes of interest, it is important what form the mix of uses take. For example, one study in Atlanta has found more mixed uses to be associated with a lower sense of community (Wood, et al., 2010). The authors note that this negative association existed when an area had a mix of uses without other elements of walkable design – i.e. there was a mix of residential uses and big box retailers with large setbacks. Therefore, it is important for planners to not focus on a mix of uses alone, but incorporate a variety of elements needed for thriving communities. Nonetheless, comparing neighborhoods with a bundle of traits such as mixed-use, walkable, and compact compared to dispersed, car dependent, and single-use, can make it difficult to determine the magnitude of the effects of a single characteristic.

Evaluations of land uses and impacts vary in their specificity and have become more sophisticated as the research area matures. The most basic analyses focus on only a single factor, like density or diversity of land use. Regression analysis of multiple factors has the benefit of determining the relative magnitude of each factor. Finally, arguably the most valuable method analyses multiple factors as well as demographic variables, which can distinguish how much of an effect is due to self selection, e.g. people who already like walking choosing to live in a walkable neighborhood (T. Litman & Steele, 2012). In addition, more precise metrics have moved from coarse (census tract or larger) proxies, to finer grain measurements that capture neighborhood variations, such as number of street intersections and mix of walkable uses. Composite measures have been found to be more consistent predictors both for mixed-uses and walkability (Vargo, Stone, & Glanz, 2012; Wood, et al., 2010). Furthermore, precise measures may no longer necessarily depend on local or hand collected data. Vargo et al (2012) have recently had good success predicting walking outcomes with composite measures using publicly available data from Google, including the existence and connectivity of sidewalks.

Some of the metrics of development patterns commonly used in sustainability literature include:

- **Density.** In the urban form literature, this is typically measured by either people per acre or, for residential neighborhoods, dwelling units per acre. For regional studies, it is typically measured at the city, metropolitan, or county level. Particularly in transportation studies, the metropolitan area may be broken down to the CBD (central business district) and the outer area. As mentioned above, it is an imprecise proxy for form, particularly at the neighborhood level.

- **Transit accessibility.** The amount of access that people have to public transit may be measured (inversely) by the average distance that one must travel from a given dwelling unit or employment location in order to reach the nearest transit stop. Other measures that are easier to calculate include the density of transit stops in an area, the density of transit routes, and the average distance in between transit stops (R. Ewing & Cervero, 2010a). The measure does not often incorporate the robustness of the transit system, and therefore is limited in its ability to indicate the willingness of travelers to use transit.

- **Street intersection density** and the related measure of street connectivity distinguish between land uses along the continuum of winding road networks with many dead ends and dense grids with short blocks. High intersection density shortens distances between destinations and provides more route options for drivers and transit networks. Both of these things can help to reduce traffic bottlenecks, improve the transit network, and make alternative transportation modes more viable. This is the land use measure most strongly associated with an increase in walking and bicycling for transportation, and it also is one of the stronger land use drivers of VMT (R. Ewing & Cervero, 2010a).

- **Sprawl indices**. The most widely used is one published in 2003 which relies on combining many variables to represent density, land use mix, degree of centering, and street accessibility (R. Ewing, R. Pendall, et al., 2003). These are discussed in more detail above.

- **3D + R is a commonly used measurement method for walkability**. Lee and Moudon (2006) have proposed a simpler alternative to measuring land use mix and street connectivity to predict walking behavior. Walking is more sensitive to detailed environmental characteristics compared to driving, thus, parcel-level data in GIS may offer economic and valid ways to quantify the built environment. Using parcel-level data, Lee and Moudon (2006) developed a process to identify variables and measures that are associated with walking. Variables strongly correlated with walking were grouped as destinations, distance, density, and route: the 3Ds + R. Distance measures to a variety routine daily destinations, supplemented with density measures and the directness of the walking route, are shown to be simple and effective alternatives to complicated composite measures often used to capture land use mix and street connectivity. This method can serve as the core constructs to quantify neighborhood walkability for policies aimed at promoting walkable communities. The authors also found that distance along a route to a variety of destinations better captures street connectivity than measures such as intersection density or block size.

4.2 Indices of Sustainable Development

Communities need way to track their progress towards the elusive goal of sustainability. It is increasingly recognized that community well being depends on the provision of ecosystem services, social vitality, equality of opportunity, political participation, and other attributes not captured in traditional metrics and rankings such as unemployment and property values. Several organizations have stepped up to provide credible indices of sustainability to aid communities to take stock of the current status, set goals for the future, and measure progress towards community objectives. They exist for a continuum of scales from the neighborhood level up to the national.

- **Neighborhood Vitality Index (NVI):** Several localities have developed customized neighborhood vitality indices to suit their local needs. These indices are designed to be used at the neighborhood level to identify disparities in health between different neighborhoods in the area. An effort by the Action for Neighborhood Change (ANC) in Toronto has published a report about their index which includes details and rationale for all metrics included: http://www.unitedwaytoronto.com/downloads/whatWeDo/reports/ANC_neighbourhoodVitalityIndex.pdf

- **Cumulative environmental hazard inequality index (CEHII)** summarizes socioeconomic inequalities in exposure to environmental hazards including particulate matter, nitrogen dioxide, diesel particulate matter, and estimates of cancer risk. Importantly, it identifies areas with high cumulative risk from all the factors included.

- **STAR Community Index** is a national sustainability rating system and framework developed by the International Council for Local Environmental Initiatives (ICLEI). The index provides a comprehensive set of performance measures by which to track and compare progress towards economic, social, and environmental goals. http://www.starcommunities.org/

- **National Neighborhood Indicators Partnership (NNIP):** This partnership runs the NNIP Shared Indicators System which aims to assemble national and local data on shared indicators of human well-being for the country, allowing location comparisons. They plan to update and share the data on an ongoing basis. http://www.neighborhoodindicators.org/activities/projects/nnip-shared-indicators-system

- **The Genuine Progress Indicator (GPI)** is an economic indicator promoted as a more accurate measure of total economic welfare than the GDP. It adjusts personal consumption with measures of income distribution, environmental costs, crime, pollution and more, and adds non-market activities such as volunteering and household work (Kubiszewski et al., 2013).

- **Ecological footprint** is a measure of humanity's demand on nature by determining how much biologically productive land is necessary to provide humans with the goods and services to sustain society. This measure helps highlight our current overconsumption of land and the increasing need to plan for sustainable land use. **Biocapacity** is a related measure of the productive land available, given current technology. Research has shown that biocapacity per capita has been declining since data has been available in the 1960s (Kubiszewski, et al., 2013).

- **The Social Vulnerability Index (SoVI)** combines 32 variables to provide an indicator of the social vulnerability to environmental hazards on a county scale for the entire U.S.. The index synthesizes variables that have been identified in the research literature to be correlated with increased difficulty of a community to prepare for, respond to, and recover from disaster (Emrich & Cutter, 2011; Hazards and Vulnerability Institute, 2012).

- **Wisconsin County Health Rankings.** While community health assessments are often performed by county health departments, they are not often widely publicized. The University of Wisconsin Population Health Institute has published county level health rankings each year since 2003 to elicit public discussion and action. An assessment of this strategy concluded that the strategy had resulted in good media coverage across the state, and that local public health officials used the ranking for a variety of purposes, including identifying program targets (Rohan, Booske, & Remington, 2013).

- **An indicator of obesogenic environments for youth** has been developed, which incorporates GIS-based measures of walkability, access to parks, quality of parks, density of fast-food restaurants, and distance to supermarkets. The indicator is meant to expand beyond simply walkability to capture both "playability" and access to healthy food (L. D. Frank et al., 2012; Saelens, Sallis, et al., 2012).

- **A HUD, USDA, DOT, and EPA document on rural communities outlines performance measures for success promoting rural prosperity**, including several for agriculture (Partnership for Sustainable, United States. Dept. of, United States. Dept. of Housing and Urban, United States. Dept. of, & United States. Environmental Protection, 2011):
    - rate of agricultural land lost to development
    - percentage of prime agricultural land placed under permanent conservation easement

- **Indexes of Biotic Integrity (IBI)** are multimetric indexes that have been developed and tailored to specific ecoregions and waterways. These indexes are constructed to evaluate overall ecosystem health, or more specifically the impact of anthropogenic influences on ecosystem health, using simple algorithms based on relatively easily measured physical and chemical attributes of surface water systems expected in specific ecoregions or areas with similar background characteristics. These tools have utility in assessing cumulative environmental impacts to surface waters that can then be useful in assessing performance of a strategy for achieving sustainable resource management of these systems. In addition, IBI can be used to identify the threshold proportions of riparian zones to developed land use that must be maintained within a watershed to sustain biotic integrity (Steedman, 1988; Yoder & Rankin, 1996).

- **An Index of Urban Environmental Quality (UEQ)** has been published that uses landsat imagery and U.S. Census data to measure and rate four factors: greenness, crowdedness, economic status, and scenic amenity. Though communities may have different prioritization for the most important factors of urban quality, the method illustrates an effective way to combine satellite images and census data into a composite index that planners can use to track progress in the urban environment (Liang & Weng, 2011).

- **Green area ratio (GAR)** is a site level metric of green surface cover of a parcel. It has been proposed for inclusion into the Washington D.C. zoning code, which will mandate a minimum proportion of green cover to impervious surface cover on a parcel (Keeley, 2011). It is intended to improve stormwater treatment, alleviate the heat island effect, and improve air quality and aesthetics. Critics note that such a requirement may create a perverse incentive for low density development on large lots, and penalize high density developments that use space efficiently.

5 Land Use Patterns Show Causal Relations to Economic, Health, and Environmental Impacts

5.1 What neighborhood scale land use qualities are most important for advancing sustainability?

Prime land for human settlement and agriculture is dwindling. . Over the past 25 years, land consumption per person has increased from 0.29 acres in 1982 to 0.36 acres per person in 2007 (ERS, 2009; U.S Census Bureau, 2012). The optimization of land use is becoming increasingly important to meet the diverse and sometimes competing needs of society for housing, food, fiber, clean air and water. If anything stands out from this synthesis, it is that compact, verdant development advances many of the important outcomes identified. To achieve this form, regional and multidisciplinary coordination is essential. Urban form at the neighborhood and regional level is inextricably tied to transportation investments. The layout and composition of the transportation network drives whether an area becomes compact or dispersed, multimodal or automobile dependent, mixed-use or single-use, and whether an area promotes or limits accessibility.

The top few elements of the land use, design, and transportation that were identified in the literature to have the strongest impact on a number of important outcomes have been summarized in the figure below. However neighborhood and regional needs vary widely, and it should be kept in mind that the elements identified below can be achieved in a diversity of ways, that match the context of the place, whether it be a rural village, coastal town, or metropolis. Decisions on land use and transportation investments may be driven by developers' cost considerations, local and regional government investments, and zoning requirements. As research on the built environment matures, the associations here should be teased out to describe the fundamental characteristics of human settlements that support sustainable living.

Table 2 Neighborhood land use qualities and positively associated outcomes

Outcomes	Land use qualities	Reference
Walking for transportation	transit stops intersection density housing age mixed-use	(Ewing and Cervero, 2010b) (Ewing and Cervero, 2010b) (Brown, 2009) (Duncan et al, 2010)
Walking for leisure	perception of safety pleasant aesthetics	(Frank et al, 2008; Doyle et al, 2006) (Frost et al., 2010)
Park use	park quality park amenities	(Tucker et al, 2008; Kaczynski et al, 2008) (Tucker et al, 2008; Kaczynski et al, 2008)
Lower Obesity/BMI	walkability transit-oriented development (TOD)	(Brown, 2009; Doyle et al, 2007; King et al, 2011) (Brown, 2009)
Lower Driving/VMT	intersection density job accessibility by auto	(Ewing and Cervero, 2010b) (Ewing and Cervero, 2010b)
Transit use	intersection density distance to transit stop TOD	(Ewing and Cervero, 2010b) (Ewing and Cervero, 2010b) (Mumford et al, 2011)
Traffic safety	low sprawl index more walkers and bicyclists	(Ewing, Schieber and Zegeer, 2003; Frumkin, 2002) (Jacobsen 2003)
Lower crime	greening/infill vacant parcels	(Branas, 2009)
Social Capital	mixed-use and walkable density ~40 units/acre housing age diversity	(Leyden, 2003) (Bramley et al, 2009) (King, 2013)
Mental well-being	exposure to greenspace	(Day, 2008; Kaplan, 2001; Bowler, 2010; Kuo, 2001)
Diversity	mix of housing types	(Talen, 2008)(Lovejoy, Handy, and Mokhtarian, 2010)
Lower health disparity	green neighborhoods	(Mitchell and Popham, 2008)
Low capital or service cost	compact development green infrastructure/low impact development open space	(Strategic Economics, 2013 and Smart Growth America, 2013) (Environmental Protection Agency, 2007); (Odefey et al., 2012) (Fausold and Lilieholm, 1999)

Fewer extreme heat events	compact development pattern	(Stone et al, 2010)
Cooler air temperatures	parks and tree cover	(Environmental Protection Agency, 2008); (Yu and Hien, 2006)
Property values	walkability TOD adjacent large parks (too contingent)	(Pivo and Fisher, 2011) (Polzing, 1999) (Larson and Parrings, 2013; Fausold and Lilieholm, 1999)
Retail revenue	walkability trees	(Leinberger and Alfonzo 2012) (Wolf, 2003)
Air pollution (immediate vicinity)	density traffic congestion accessibility by auto urban areas	(Melia, 2011) (Sarszynski et al, 2006) (Zhou and Levy 2007; U.S. Environmental Protection Agency 2013) (Alberti, 2007)

5.1.1 Active transportation, physical activity, health, and social well-being

For encouraging alternative transportation, physical activity, and the attendant health benefits such as cardiovascular fitness and reduced risk for obesity, a bundle of neighborhood characteristics is most effective. These characteristics are a dense street grid (with few dead ends and cul-de-sacs) to minimize travel distance, a mix of everyday uses within walking distance from homes and workplaces, moderate to high average density, access to parks and green elements such as street trees, and design characteristics that facilitate Walkability.

While a dense street grid is one of the most important land use characteristics for the encouragement of walking for transportation, it is unrelated or even mildly detrimental to the encouragement of walking for leisure (Oakes et al, 2007).

In rural areas, physical activity is most associated with pleasant aesthetics, trails, safety, parks, and walkable destinations (Frost, et al., 2010). This complicates the quest for the ideal land use conditions to encourage overall physical activity. The perception of safety is critically important for community walkability . Though safety and perception of safety can be influenced by land use choices such as a mix of uses that provide around the clock activity, street trees, and infill or greening to eliminate vacant lots (Branas, et al., 2011).

For supporting mental health and social capital, an overlapping, but different set of characteristics have the largest positive impact. These include high exposure to greenspaces, moderately high density around 40 units per acre, a mix of uses and housing types, and walkability as measured through qualitative audits.

Compact, walkable neighborhoods are not only beneficial environmentally and socially, but they are also desired by consumers. Support for mixed-use traditionally designed communities has grown from 44% in 2003 to 59% in 2005, though support is lower in rural communities and among those who expect such communities to have space limitations (Handy, Sallis, Weber, Maibach, & Hollander, 2008). The National Association of Home Builders (2001) identifies a trend towards mixed-use communities with neotraditional design and predicts that future neighborhood will have smaller lots, narrower streets, and less paved area. Furthermore, there is more demand for walkable and transit accessible neighborhoods than is currently being met (Carnoske, 2010). Specifically, TOD often appears to have higher economic returns than other forms of development, even those considered smart growth. Large parks also increase values for adjacent properties, and residential neighborhoods are particularly affected (Fausold & Lilieholm, 1999; Larson, 2013).

Box 23. SHC Product Highlight:

DASEES (Decision Analysis for a Sustainable Environment, Economy, and Society), in SHC Task 1.1.1.2, is a stakeholder collaboration tool that guides users through a decision analysis framework to help participants build common understanding of complex problems and identify solutions. This tool helps communities collaboratively answer the questions "Which values are important to my community and what decisions help to reach those values?" It is intended to be adaptable to address specific sustainability issues that arise from the Theme 4 decision sectors. It is adaptable both in regards to the problems it analyzes and the scale of the issue, which are user defined. A prototype of the tool usable by experienced modelers will be available in September 2013, however, a user-friendly version that includes a menu of common decisions communities make should be available online near the end of 2014.

5.1.2 Climate change and extreme heat events

To mitigate and adapt to climate change through neighborhood scale interventions, promising techniques are green infrastructure, including street trees, urban forestry, and parks to sequester carbon, as well as transit oriented development, to encourage residents to reduce automobile transport. These same interventions impact air quality in other ways, which can affect human health. Green infrastructure helps scrub the air of pollutants that can aggravate asthma and upper respiratory disease (Cavanagh, et al., 2009; Francisco J. Escobedo, et al., 2008). In addition, evidence has quantified the ability of green roofs, street trees, and more to cool air temperatures, potentially mitigating the urban heat island effect (Environmental Protection Agency: Office of Atmospheric & Environmental Protection Agency: Climate Protection Partnership, 2008; Yu & Hien, 2006).

On the other hand, TODs typically have higher levels of air pollution on site, though emissions per capita are greatly reduced (Haas, 2010). This is likely true of many compact neighborhoods. An important research need going forward is to understand the magnitude of the tradeoff between elevated local emissions and reduced regional emissions, and to what degree that can be mitigated through green infrastructure. Particularly for coastal communities experiencing sea level rise, climate adaptation may be a more pressing land use need than mitigation. Here again, green infrastructure offers some options. A direct approach may involve converting developed areas closest to the coast to low intensity uses such as parks and boardwalks.

More proactive measures to hold the line, rather than retreat, include maintaining protective dunes, reefs, and wetland areas (Arkema et al., 2013; Barbier, et al., 2013). A recent analysis showed that maintaining existing reefs and coastal vegetation fully intact could halve the number of people, vulnerable populations, and property exposed to coastal hazard by the year 2100 (Arkema et al., 2013).

5.1.3 Environmental Justice and Neighborhood Urban Form

Finally, the literature provides substantial evidence for links between urban forms and environmental justice issues. First, socioeconomically disadvantaged neighborhoods are disproportionately located in areas with higher health burdens and lower access to services. Low socioeconomic status (SES) communities on average have lower access to supermarkets and higher access to fast food outlets, which is linked to obesity (R. P. Lopez, 2007) (L. Frank et al., 2009). Disparities between socio-economic groups exist with regard to access to, and usability of, parks and green space. They have less urban vegetation and lower park space per capita (Boone et al, 2009 and Sister et al, 2010), exposing those communities to greater risk of Urban Heat Island effects (Jenerette, Harlan, Stefanov, & Martin, 2011). Low SES neighborhoods also tend to score lower on measures of walkability (Sallis et al., 2011), are more often located near to industrial land uses (Abel & White, 2011; Maantay, 2001), and are more often located near to highways (R. Lopez, 2006), leading to community disruption, lower walkability, and higher air pollution exposure. Considering public safety, design elements, and amenities can improve the access to and usability of parks and green space for a broader demographic spectrum.

Second, certain community design and urban form patterns impose a disproportionate burden on vulnerable groups, no matter where they live. For example, a sprawling urban form that separates residences and destinations, a lack of transit, and broken sidewalks all impair the mobility of those who are unable to drive, whether due to age or a physical handicap (Kochtitzky, et al., 2011). Youth are the most underrepresented demographic group in walkable neighborhoods, perhaps more so than low-income and minorities (Cutts, et al., 2009). More research is needed to reveal how demographics and other community attributes mediate impacts of urban form. For example, though it is well established that when holding all else equal good pedestrian design leads to more physical activity and lower obesity, other community factors have a larger impact that can negate this effect. The perception of a lack of safety has been shown to dampen the benefits of a walkable neighborhood (L. D. Frank, et al., 2008).

It is important to keep in mind that the relationship between environment and equity is not one-way. Equity impacts environmental choices and environmental quality as well. Research has shown that countries with more equal income distribution, great political rights, and higher literacy tend to have clean air and water (Torras & Boyce, 1998; Wilkinson, Pickett, & Vogli, 2010). Wilkinson et al (2010) cite three primary supported reasons why equality is actually a precondition for sustainability: 1) inequality makes people more materialistic and less likely to have positive attitudes towards the environment, 2) more equal societies engender more feelings of collective responsibility, and 3) more equal societies are more innovative, as measured by patents per capita.

Box 24. The Community-Focused Exposure and Risk Screening Tool (C-FERST) and Tribal-FERST are being developed in SHC Task 2.2.1.5. These web-based decision support tools are designed to help identify and prioritize local environmental issues. They are still in development however they have great relevance to land use.

The tools allow users to: follow walk-through guidance and strategies for conducting community and tribal assessments; identify relevant local environmental issues; download information on these issues; map 5 exposures and risks; prioritize their community's issues; explore potential solutions; and link to other community-relevant tools including EPA/ORD's National Atlas. T-FERST and C-FERST are emerging tools that will help decision makers identify environmental health issues in their communities, identify priorities in the context of limited resources and competing interests and address them effectively.

5.2 What regional land use qualities are most important for advancing sustainability?

5.2.1 Regional coordination to avoid unintended consequences

The pattern and form of regional development contributes to achieving sustainable communities. In the United States, urban land is projected to increase from 3.1 % in 2000 to 8.1 % in 2050 under a business as usual scenario (D. J. Nowak & Walton, 2005), which will consume fertile farmland, essential forests, and other land that provides necessary ecosystem services. Regional planning, growth controls, and incentives can contribute to containing this expansion, building up rather than out, while improving livability at the same time.

Though the exact thresholds and ranges necessary to qualify urban and regional form as sustainable are not yet clearly defined, it is clear it involves a balance. Achieving sustainability means balancing compaction and congestion, liveliness and intensity, greenfield preservation and access to parks and greenspace. For example, compact cities decrease emissions on a regional scale, however higher population and without strong transit systems, experience higher congestion, and higher emissions within the city.. One European study indicates that moderate density cities may have the lowest energy usage, however this may be due, in part, to differences in disposable incomes, as the study incorporated air travel. This type of comprehensive comparative energy use study has yet to be done in the United States.

It is important that this development is coordinated on a regional scale to take into consideration both the urban area, rural area, and any neighboring towns and cities. Planning in this way may help to prevent spillover effects. For example, over-restricted growth or over-restricted land use types may be displaced to adjacent jurisdictions without regional cooperation. Within the same jurisdiction, a regional perspective can ensure informed siting for new developments

The top few elements of the land use, design, and transportation that were identified in the literature to have the strongest impact on a number of important outcomes have been summarized in the figure below.

Table 3 Regional land use qualities and positively associated outcomes

Outcomes	Land use qualities	
Less Driving/VMT	centralization density job accessibility by auto mix of all is cumulative	(Ewing and Cervero, 2010b) (Ewing and Cervero, 2010b) (Ewing and Cervero, 2010b) (Litman, 2012; Su 2011; Ewing and Cervero, 2010; Cao, Mokhtarian, and Handy, 2006)
Transit use	fewer parking spaces	(Sinha, 2003)

	intersection density	(Ewing and Cervero, 2010b)
Traffic safety	low sprawl index	(Ewing, Schieber and Zegeer, 2003; Frumkin, 2002)
Social Capital	shorter commute time accessibility	(Besser et al, 2008) (Holt-Lunstad, Smith, and Layton 2010; Besser, Marcus, and Frumkin 2008; Christian 2012a, 2012b; Fujiwara and Kawachi 2008; Dickens et al. 2011)
Emotional well-being	shorter commute time	(Miles et al, 2011)
Productivity	efficient transit density	(Nelson and Peterman, 2000) (Cervero, 2001)
Low infrastructure cost	density	(Burchell et al, 2000); (Choi and Fricke, 2010); (AKRF Inc, 2011); (Deal and Schunk, 2004); (Chang et al, 1999); (Muro and Puentes, 2004)
Clean air (in region)	compact development pattern	(VandeWeghe and Kennedy, 2007 and Alberti, 2007)
Low residential energy use	moderate density (24-32 units/acre)	(Holden and Norland, 2005)
Land conservation	compact development pattern	(United States Environmental Protection Agency, 2001) , (McLaren, 1992)
Construction jobs	growth management policies	(Emerging Trends in Real Estate 2002, PriceWaterhouseCoopers and Lend Lease Real Estate Investments, LLP, 2002.)
Personal income	growth controls	(Florida, 2000)
Traffic congestion	density compact development pattern	(Sarszynski et al, 2006) (Sarzynski et al, 2006), (Melia, Parkhurst and Barton, 2011)
GHG emissions per capita	low density prosperity	(VandeWeghe and Kennedy, 2007 and Alberti, 2007) (Hienonen et al, 2011)
Extreme heat events	sprawl	(Stone et al, 2010)

5.2.2 Compact Development Pattern

Perhaps the largest issue surrounding land use and development is sprawl. As people move away from inner cities and out towards less developed land, urban abandonment is being found in more and more large cities. Economic disinvestment is a major concern for these inner city areas. Outside of cities, in suburban or rural areas, land use becomes a major issue when natural land is converted to built environments. In addition to disruption of ecological functions and land contiguity, sprawl can lead to increasing stressors on natural resources. For example, increasing demand for development leads to much higher water usage, and concern for contamination and infiltration of runoff into local rivers and streams magnifies.

Land use and transportation decisions affect and constrain each other. Building a compact mix of uses lessens the need for long trips, and can potentially lower congestion and decrease the demand for new roads. Conversely, new highway construction divides neighborhoods physically and psychologically, and speeds the expansion of development to new areas. Though any individual land use element appears to have a small effect on transportation mode choice and VMT, they are cumulative and reinforcing. Smart growth plans which integrate multiple land use changes have been shown to reduce vehicle ownership and travel by 20-40% (T. Litman & Steele, 2012). Overall land use pattern matters; the perfect new urbanist development built in a remote location will still generate more VMT than a single use neighborhood in the urban core. Research shows that the most impactful variable on travel behavior is destination accessibility. Land use elements such as compactness, centeredness, design features, and mixed uses all affect how accessible destinations are, and which transportation modes will be most efficient. To affect travel behavior through land use policies, it is necessary to think in terms of how the policies affect destination accessibility, which is strongly correlated with less driving and more walking, cycling, and transit-riding. Destination accessibility is a product of development density, land use diversity, and both the design and operation of the entire transportation system. Destination accessibility is typically defined by whether individual travelers have a large proportion of different types of destinations reachable within a reasonable timeframe and at a reasonable monetary cost. Although residents of a dense, mixed-use, walkable, safe, pleasant neighborhood are likely

Box 25. Green Communities Program

The EPA's Green Communities Program provides communities with access to a wide array of planning tools and information relevant to sustainability issues. The presentation of the tools and information is organized around a five-step collaborative planning process, which the tools and information are meant to help communities implement:

Step 1, Community Assessment: Look holistically at the present state of the community.

Step 2, Trends Analysis: Determine what the future state of the community will be in a "do-nothing" scenario.

Step 3, Visioning Process: Decide what future state (or states) it is desirable for the community to achieve and can be arrived at through appropriate actions.

Step 4, Sustainable Action Plans: Create an action plan for achieving to have lower rates of vehicle-miles traveled (VMT) than residents of other neighborhoods, the neighborhoods with the lowest VMT per capita are ones located in the cores of urban areas, where residents of a given neighborhood have high rates of accessibility both to destinations within their own neighborhood and to those in a large number of other neighborhoods. Destination accessibility is also an important driver of economic activity and differences in accessibility between neighborhoods can exacerbate socioeconomic disparities.

Reducing VMT does not only contribute to environmental goals, such as lowering overall air pollution levels, but also to livability. Reducing commute time reduces frustration and increases leisure time. And congestion has impacts on the people living near it. Holding density constant, living in an area with more auto commuters is associated with more depressive symptoms.

Parking availability is less studied, however also influences people's decisions about whether to drive, walk, or take transit. In addition, a plentiful supply of parking decreases demand for public transit. Zoning codes typically provide minimum parking requirements based upon peak usage, and no maximums. In some cities, off street parking spaces alone are estimated to take up over 20% of urban land (Mid-America Regional Council, 2010). Offering more efficient parking options and increasing transit use has the potential to more effectively use land, through infill projects, for parks, and to reduce usage of greenspace. In addition, minimizing the space used by parking lots may also encourage walking and biking, by reducing travel distances between destinations.

The impact of urban form on transportation has implications for energy use and climate. On a per capita basis, holding income constant, GHG emissions are significantly lower in denser, more compact cities (M. Alberti, et al., 2007; VandeWeghe & Kennedy, 2007). Because climate change is a global issue, contributions to climate change also need to be evaluated from a holistic perspective that incorporates both production and consumption. When household air travel is included, prosperous dense cities begin to have higher energy consumption and climate footprints. Some hypothesize, with some supporting data, that this effect may not entirely be due to prosperity, but that a lack of private greenspace in the densest cities may motivate people to fly to the countryside for vacations (Holden & Norland, 2005). For this reason, they found, at least in the context of Norway, that medium density cities (between 24 and 32 dwellings per acre) are the most energy efficient.

Regional planning for environmental sustainability often addresses balancing intensity and density of use with compaction that preserves greenfields. Denser areas have been correlated with increased deforestation and invasive species, however this may be a result of the densest areas also being the highest in overall population. More compact cities of similar population levels actually have more biodiversity within the region; probably because more open space is preserved to provide habitat.

Compact cities also appear to experience fewer extreme heat events. This is also assumed to be due to regional cooling effects provided by the lower impervious surfaces overall. To understand this effect, impervious surfaces must be measured on a per capita basis, rather than a per unit area basis. Measured on a per unit basis, more compact regions typically have higher impervious surface levels than areas with many personal lawns. However when measured on a per capita basis, compact towns and cities accommodate more people with lower impervious surfaces. However research explicitly comparing the impervious surface loads of compact versus dispersed regions is lacking.

5.2.3 Accessibility and Affordability

Most social and human well being effects are seen at a smaller neighborhood scale, and understandably so. Compactness at a regional level isn't clearly associated with BMI and only weakly with walking. However, research does support a few conclusions. Those with shorter commute times enjoy higher levels of social capital, more frequent social trips, and fewer depressive symptoms. Unfortunately, though compact cities lessen driving distances, they do not always lead to shorter commute times due to congestion.

Transportation and land use decisions have impacts beyond those on energy use and travel behavior. Urban patterns that widen the distance between homes, jobs, and other destinations cause many households to spend more time and money on transportation. For some, this pattern imposes a disproportionate burden. For the physically handicapped, elderly, or youth who can't drive, long distances between destinations and a lack of public transit may constitute an insurmountable barrier to mobility. Handicapped accessibility used to be an issue focused solely on building and site specific features. However it is increasingly clear that accessibility is an important issue at the neighborhood and regional scales as well. Dannenberg et al, (2003) cites the need for research to evaluate the health and social well-being impacts of transportation policies and single-use residential patterns on persons with disabilities. Density, when it increases the proportion of high-density housing such as apartment and row houses, may lessen socioeconomic disparities in another way as well, through reducing residential income segregation and improving access to transit and public services.

On the other hand, housing in denser areas frequently costs more per square foot. This can be offset by lower transportation costs, but whether these savings outweigh the costs can depend on many factors. The Housing + Transportation Affordability Index, supported by the Center for Neighborhood Technology (CNT), attempts to calculate this for users. The tool allows users to search a nationwide map for their metropolitan area, and compare housing affordability to affordability with transportation cost estimates included. The index illustrates that in many areas, including transportation costs in affordability estimates often can highlight more central locations as more affordable.

5.2.4 Minimizing costs and maximizing vitality

Research on the economic impacts of the regional development pattern fall the categories: infrastructure costs, the impacts of growth controls, and the business benefits of various development forms.

Denser development generally incurs lower infrastructure costs, and certainly has a lower infrastructure cost to tax revenue ratio on a per acre basis. Respected economist and Federal Reserve Vice Chairman of the Board of Governors of Rhode Island, Edward Gramlich (2002) has stated that "the application of smart growth strategies over the next twenty-five years could save as much as $250 billion, mainly in the form of infrastructure investment." On the other hand, density may not have an association with public costs overall, though research that is able to measure density at a neighborhood scale is necessary to refine this finding.

The presence of growth management measures is positively associated with overall personal income levels in a metropolitan area (Florida, 2000). Whether this is because areas with growth control measures improve wages, or attract higher income residents, or if regions with higher incomes are more likely to implement growth controls is not clear. However it does seem clear that as long as they are accompanied by appropriate modifications to policy and regulation, growth controls do not threaten housing affordability.

Cities may be able to improve their productivity and market demand through regional land use actions. First, cities that have an efficient and integrated system of transit, also boast higher productivity levels (Nelson & Peterman, 2000). Second, denser areas may hold the economic benefit of agglomeration, increasing labor productivity. Finally, there is evidence of unmet demand in city centers, both for walkable residential communities as well as for retail. The Initiative for a Competitive Inner City (ICIC) estimates that about 25% of inner city retail demand is unmet (National Association of Local Government Environmental & Smart Growth Leadership, 2004).

6 Decision Science and Land Use Practices

6.1 What practices best support these land use qualities?

Where do we go from here? With the era of sprawl came the belief that single-use zoning was the best method for land development and the desire to avoid mixing of uses. Traditionally, factories and industry were built near the city. This provided an adequate labor pool within a reasonable commute to and from work. Thanks to advances in manufacturing and pollution control, there is now less need for industry to be separate from other zoning categories. An alternative to sprawl would be the concentration of people, resources, and economic activity. High population densities and compact urban design support walkable neighborhoods and mass transit alternatives to the automobile.

Empirical evidence suggest that developing at higher population and employment densities results in closer trip origins and destinations, on average, and thus in shorter trip lengths, on average. This compact urban development coupled with high residential and employment densities can reduce energy consumption, vehicle miles traveled, and carbon dioxide (CO_2) emissions (National Research Council, 2009). Concentrated populations can also save land for agriculture, wildlife, and habitat by using less land for urban development (Seto, et al., 2010). In addition, several sustainability advantages of cities and urban areas with larger populations are the economics of scale in terms of providing infrastructure, education, healthcare, transportation and sanitation services (L. Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007) as well as increasing returns from innovation and productivity; and economies of scale in energy use, carbon emissions, and infrastructure provision (Seto et al., 2010). Rural communities too, may benefit from more compact development. Clustering rural development has been shown to not only reduce the open space consumed, but also reduce impervious surfaces, typically by 10-15% (United States Environmental Protection Agency, 2001).

Recently, a number of related and overlapping philosophies for designing healthy neighborhoods have developed, including smart growth, New Urbanism, traditional neighborhood design, transit-oriented development, lifelong communities, cluster development, conservation development, and infill development. What these philosophies have in common is the promotion of a mix of uses and housing types in a form compact enough to support walking and bicycling for short trips. And there is some evidence they effect change. Metropolitan areas with reform oriented zoning and conservation funding have lower land consumption per capita (R. I. McDonald, et al., 2010).

Growth controls have gained traction to curb the unfettered expansion of suburban development. These include a variety of strategies to restrict or incentivize development within the boundaries of the existing municipal infrastructure networks. Development already is hastened in areas with infrastructure provided, and this approach can be successful at counteracting the tendency to construct residential uses close to open space and far from high density areas (Irwin & Bockstael, 2004).

However if demand exceeds the supply of eligible parcels, very restrictive growth controls can cause development to leapfrog to neighboring jurisdiction. Such a pattern can exacerbate traffic congestion, drain tax funds, or unintentionally burden neighboring jurisdictions with the same concerns. To gain the environmental and public health benefits of minimizing sprawl, while avoiding leapfrog development, it is suggested best practice to increase allowable residential densities within the service area, which reduces demand to build housing outside the jurisdiction (Phillips & Goodstein, 2007). Practices such as a transfer of development rights (TDR) can aid in this goal (Nelson, 2012). This can be achieved without costing property owners who would rather sell their land. The mechanism allows an agricultural or open space land owner outside the growth boundary to sell their rights to develop to a landowner in a designated development zone. Typically this transfer allows the buyer to build to a higher density than would have otherwise been permitted, and requires the farm owner to enter into a permanent conservation easement.

Achieving a balance between incentivizing compact development and preventing leapfrog development remains a challenge for community planners, one which may benefit from tools to aid coordinated regional planning and scenario modeling.

A few of the practices with generous research supporting their benefits are discussed below.

- **Comprehensive plans and sustainability plans.** According to an APA survey of 890 local planning department staff found that 27% of jurisdictions had officially adopted comprehensive plans that address public health, while only 3% had sustainability plans that addressed public health (Hodgson, 2011). This illustrates a both a tepid adoption of sustainability plans (less than 16%) as well as a lack of general recognition of the interdependent nature of land use sustainability and human well-being. While topics such as recreation, public safety, clean water and air, and active transportation were present in over half of comprehensive plans, very few (less than 10%) addressed obesity prevention, social capital, mental health, food security, and health disparities.

- **Compact development.** Many professional and political institutions, including the Urban Land Institute, the American Planning Association, the President's Council on Sustainable Development, the European Environment Agency, the United Nations, and the National Research Council, support the conclusion that a compact city form is more sustainable than a disperse one. Compact development conserves more land, improves air quality, increase biodiversity, and improves traffic safety, and leads to less driving, lower GHG emissions, fewer extreme heat events, and lower public infrastructure costs. Tradeoffs include the potential for higher congestion, more local exposure to air pollutants, higher housing prices, and a mixed impact on commute times.

- **Health Impact Assessment (HIA)** is defined as a "combination of procedures, methods, and tools that systematically judges the potential, and sometimes unintended effects of a policy, plan, program or project on the health of a population and the distribution of those effects within the population (Quigley et al., 2006)." In addition, HIAs typically provide optimal management actions to address the effects identified given complex tradeoffs (de Nazelle et al., 2011). Because they provide decision makers with explicit measures of impacts and recommended actions, they can be useful in garnering additional funds for a project (Ross et al., 2012). Such assessments can be very useful to determine in advance any overlooked environmental justice consequences to a project. This HIA methodology is relatively new, however is rapidly gaining traction (Wernham, 2011). For example, the Healthy Development Measurement Tool has spread to multiple cities in just a few years.

- **Infill development** is development of new uses in a previously developed area. It may involve increasing the intensity of use of a parcel, developing unused land that is surrounded by development, or repurposing previous development to a new use. Infill development can relieve development pressure on outlying undeveloped areas, improve city center vitality, improve walkability, and can benefit from existing infrastructure. Infill can be more challenging and potentially more costly than greenfield development due to the need to remove existing structures, clean-up existing sites, and piece together multiple parcels for sufficient space. However the benefits of infill may be catching on. In nearly 75% of large metropolitan areas between 2000 to 2009, infill housing development (new housing in previously developed areas) grew as a share of all new housing (US Environmental Protection Agency, 2012b). Infill is a strategy to help alleviate development pressure on agricultural land, keep development within the bounds of existing infrastructure, reduce reliance on wells and septic systems, and promote a compact development pattern.

- **Brownfield redevelopment** is a type of infill development that is particularly challenged by the added difficulty of existing land contamination that must first be cleaned up. Brownfield sites are typically abandoned or unused sites that formerly housed industrial or commercial facilities and now may contain hazardous substances. Reinvesting in brownfields has the potential to transform a community blight into a community asset. Brownfields redevelopments play an important role in improved land use decisions. By redeveloping formerly contaminated sites land in urban areas is put to reuse, rather than development consuming previously undeveloped lands and contributing to sprawl. A redevelopment project also presents the chance to develop using smart growth principles that increase urban density, provide the opportunity to build more sustainably, and revitalize urban cores. Ancillary benefits include stimulating businesses and providing jobs, both the temporary construction-related jobs and permanent jobs at the redeveloped sites. The EPA Brownfields Program (http://epa.gov/brownfields/) leverages multiple sources of funding to spur brownfield redevelopment in communities around the nation.

- **Mixed housing types and ages** may promote diversity in neighborhoods by economics and life stages. This can be fostered though form-based codes, allowing and encouraging multi-family buildings in formerly single-family zones, link high and low diversity neighborhoods by revitalizing the transitional areas with public spaces, (Talen, 2008) while ensuring neighborhood improvement efforts don't displace low income residents due to rising property values. Metropolitan areas with more mixed-income neighborhoods have higher rates of upward mobility (Chetty, Hendren, Kline, & Saez, 2013). Density however has an ambiguous relationship with diversity. Jane Jacobs promoted the two as linked, however highly dense areas can also be homogenous.

- **Transit oriented development (TOD).** Transit-oriented developments situate a mix of housing and commercial uses within a ¼ mile to a transit stop or hub. This philosophy focuses on reducing traffic and automobile dependency. It is likely that such developments command a premium in the marketplace. TOD has quantified potential to reduce GHG emissions. The Center for Transit-oriented Development has estimated that living in a TOD will on average reduce a household's driving related GHG emissions by 30% to 78%, depending upon the location efficiency rank of the development (Haas, 2010). Driving related emissions account for about 17% of total United States CO2 emissions. To support sufficient rides for rail stations, density well above the typical suburban development is necessary. Typical suburban developments are generally in the range of 2-6 units per acre and New Urbanist style single family neighborhoods typically range from 8-12 units per acre(National Association of Local Government Environmental & Smart Growth Leadership, 2004). The latter density reaches the threshold for a High Medium Location Efficient Transit Zone as identified by the Center for Transit-Oriented Development (Haas, 2010). To pass the threshold for the 2 highest location efficient transit zones, residential densities need to reach 30 units per acre. Studies of homeowner preferences indicate that this is an attainable goal., and safe places for children to.

- **Traditional neighborhood development (TND)** refers to construction of an entire neighborhood according to guidelines promoted by New Urbanism such as a mix of uses, small setbacks, homes with front porches, well connected streets, and public spaces. Though TND may occur on infill sites, in practice, they are often constructed on previously undeveloped land. Developments classified as new urbanist in style have been shown to be more effective in incorporating watershed protection techniques than conventional developments TNDs are more likely to incorporate impervious surface reduction techniques and restore degraded stream environments (P. R. Berke et al., 2003). New Urbanist neighborhoods in the study were, on average, two and half times denser than conventional developments, with 7.18 dwellings per acre versus the conventional 2.77 dwelling units per acre.

- **Urban parks and green space** have the potential to improve both mental and physical health as well as concentration and learning. They can also contribute to community cohesiveness and a sense of safety. By improving property values, boosting tourism and shopping, and reducing expenditures on grey infrastructure, urban green space can contribute positively to a city's economic outlook. Urban green space can play an important role in mitigating some of the negative effects that urbanization has inflicted on natural ecosystems. Environmental factors that are important to humans, such as clean air, clean water, urban heat islands, and carbon emission, are improved by native vegetation in the urban landscape. There is not a one-size fits all approach to greening urban space. Whether on a site, landscape, or city-wide scale, attention to environmental characteristics as well as human perceptions and needs across socio-economic groups makes for successful outcomes.

- **Low impact development**. With rapid urbanization, water problems like flooding, water pollution, and watershed degradation have become an obstacle for urban sustainability. The implementation of Low Impact Development (LID) Best Management Practices (BMPs) including impervious pavement, grass swales, filter strip/buffer, bioretention cells, and stormwater wetlands has been recommended. The concept of LID BMPs has been around for some time, although it has not been widely implemented. Several barriers exist including evidence for the effects of individual LID BMPs, the lack of an urban runoff simulation model for LID BMPs, LID BMPs planning, and the guidelines and technical codes. The lack of technical guidelines for designing, implementing, and managing LID BMPs prevents its wide application. Therefore, continued research, development of guidelines for designing, implementing and managing of LID BMPs would promote adoption of this concept.

6.2 ORD Recent and Planned Products Relevant to Land Use Decisions and Sustainability

Many of the research programs within the Office of Research and Development, including SHC, ACE, SSWR, and CSS, are already in the process of developing valuable tools and research that will support decision making around land use and address critical land use issues. The SHC Research Program is focusing on quantifying ecosystem goods and services produced by land, measuring impacts of land use choices, and providing collaborative decision support tools. ACE and SSWR has developed useful tools to compare alternative scenarios. Such tools can provide communities with the means to address critical issues identified in this document including negotiating the desired balance of compact development, local and regional air quality, impervious surfaces, green infrastructure, and open space.

For example, the EnviroAtlas and the Urban Atlas are GIS-based tools that map geography, demographics, and the production of ecosystem services, including toxics removed through tree coverage, ecosystems contributing to water quality, carbon sequestration, impervious surfaces, habitat, ecosystems that support food and fiber production, ecosystems which help mitigate natural disaster.

These tools directly address a need to expand beyond mapping land use and land cover, to mapping land function, including the ecosystem services derived from land (Verburg, van de Steeg, Veldkamp, & Willemen, 2009). Applications that are user friendly and don't require a skilled user are especially valued as a means to open the door for complex and more detailed considerations of ecosystem services and environmental justice in the everyday planning process.

Some of the future research in SHC is expected to support in depth understanding of the ecosystem services derived from land. The Ecological Production Function Library will define and catalogue ecological production functions. This product will be a resource for researchers and modelers to develop tools that quantify the ecosystem services benefits and losses expected from various land use decisions. The database is expected to be fully available online in March, 2015.

The Integrated Climate and Land-Use Scenarios (ICLUS) Online, developed by ACE, maps population and housing density scenarios through the year 2100 and models the impacts on climate change and land use change scenarios. Compact development has been identified as an important indicator of the land use sustainability of community. The ICLUS tool allows communities to estimate and visualize the long range impacts of more compact or less compact development on local and regional climate and land consumption. The underlying data is also available and could feed more complex tools to address site-specific community needs.

Future planned research in ACE is expected to address another critical community land use issue: adapting to climate change. The work will provide communities with a method to assess their ecosystem resilience to climate change through standardized metrics, and to identify particularly vulnerable sectors such as human health, water quality (ACE 163).

In SSWR, a site-based storm water calculator has been published online that estimates amount and frequency of storm water runoff from a specific site. It allows users to compare a variety of land use scenarios, including no development, impervious development, and varying levels of green infrastructure. Green infrastructure as a land use best practice can advance multiple pillars of sustainability, including reducing infrastructure and cooling costs, improving water quality, enhancing mental well-being, and more. This tool supports community use of green infrastructure by providing feedback on when and where GI is most valuable.

Future planned research in SSWR, in conjunction with SHC, will provide direct guidance to communities on the most beneficial green infrastructure practices for their needs. This product will be of direct use to community decision makers, property owners, and developers. Research in CSS also touches on land use issues at the community scale, including work to determine the risks and treatment options for bio-waste in landfills (CSS 4.1.3) and software to support sustainable industrial supply chains (CSS 5.2.4).

Below, we identify the current and planned research in ORD that is especially relevant to land use and sustainability. The work is then compared to the research needs that emerged from the literature review to identify gaps between current research and research needs. This analysis may be a useful guide for future work.

6.2.1 Quantification of Ecosystem Goods and Services, Human Health Impacts, and Identification of Thresholds and Tipping points

A broad field of environmental scientists and engineers are contributing expertise to research on land use sustainability. To further the usefulness of tools, models, and best practices, quantification of EGS is a necessary first step towards modeling linkages between the form of development and the functions critical to sustaining human life and the ecological systems.

- **A collection of 15 papers on disproportionate health risks** has been published as a product of SHC Task 2.2.3.5 in a supplemental issue of American Journal of Public Health. This issue resulted from an EPA sponsored symposium in 2010 on factors leading to disproportionate health risks. Some of the articles most relevant to land use address the health effects and disproportionate exposure to noxious land uses and health impact assessments as a process to explicitly consider equity in community decision-making. Several of these papers are cited throughout this land use synthesis paper. http://ajph.aphapublications.org/toc/ajph/101/S1

- **A review of existing Health Impact Assessments (HIAs)** is being conducted in SHC Task 2.2.1.6. The review is intended to: (1) inventory the types of community level decisions represented in HIAs in the sectors of transportation, housing/buildings/infrastructure, land use and waste management/revitalization, (2) assess the data, tools and models used in current HIAs for the four sectors, (3) crosswalk with existing Community Public Health and SHC tools, models and approaches that could have supported the HIA efforts, and (4) identify potential research focus areas to support and improve the HIA community of practice. The anticipated review will inform HIA case studies being conducted in conjunction with Region 1 and Region 4.

- **A report titled Neighborhood Scale Quantification of Ecosystem Goods and Services** will be released by SHC Task 2.1.4.1. The report provides ecosystem goods and services production functions for two alternative neighborhood development strategies, one which emphasizes green space and a suburban setting, and the second which emphasizes traditional neighborhood design and walkability. The report will be of interest to community decision makers, developers, and city and regional planners interested in how alternative development strategies affect the provision of a variety of ecosystem goods and services.

- **A peer reviewed report of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes** was produced by SHC Task 2.1.4.4. The report reviews the evidence for ecosystem services produced by the coastal wetlands of the Great Lakes including carbon sequestration, sport and commercial fish, retaining sediments and wild rice production. Their research has highlighted a need we also find: to identify quantitative relationships between land use decisions and the delivery of ecosystem services.

- **Several peer-reviewed publications that quantify, value, and estimate the production of ecosystem goods and services from Tampa Bay coastal areas** have been produced by SHC Task 2.1.4.1. This science informs decisions about the use of coastal land, and estimates the impacts of conserving, restoring, and developing the land. The science also feeds decision making tools which can provide a convenient link to the information.

- **A report on sparrow counts in Rhode Island**, developed by SHC Task 2.1.4.3, shows a marked decrease in sparrow counts in RI salt marshes since 1982 and finds anecdotal evidence that natural buffers of 150m protects against this loss. This adds to the evidence showing impacts on biodiversity from development, and the possible protective value of natural buffers surrounding sensitive ecosystems.

- **A publication on the effects of urbanization on migrating birds on the western shore of Lake Michigan** has been presented at the American Ornithologists Union. The study looked at spring migration in the Chicago region to analyze the effects of urbanization on migrating birds. The authors considered the impacts of forest patch size, distance to the Lake Michigan coastline, and surrounding urban context (urban and suburban). However, they found no simple relationships between landscape characteristics and the migratory movements and concluded more research is necessary.

- **Vapor Intrusion Assessment.** Vapor intrusion is a potential exposure pathway for sites with subsurface contamination. Because EPA and state cleanup programs often leave residual contamination at sites, vapor intrusion potentially impacts residences and businesses at contaminated sites and may present a barrier to redevelopment of brownfields sites. Brownfields reuse is a component of land use that can lead to improved communities. SHC project 3.1.2 and task 3.1.4.5 contain work on assessing the impacts of subsurface contamination. Project 3.1.2 produced a report on the fluctuation of indoor radon and volatile organic contaminant concentrations due to seasonal variation in building and climate factors. Task 3.1.4.5 which supports the office of underground storage tanks has produced work that addresses site characterization for vapor intrusion, monitoring methods to reduce costs and modeling that includes an automated uncertainty analysis to avoid previously publicized problems with model use at vapor intrusion sites.

6.2.2 Defining, Measuring and Tracking

Sustainability is a lofty and esoteric goal, however the impacts of community choices on people, the environment, and livelihoods are distinct and often measureable. Metrics and indicators help communities define their current status and track progress towards commonly defined goals.

- **Final Ecosystem Goods and Services Classification System (FEGS-CS),** under development within SHC Task 2.1.1.1, provides a standardized measurement system for classifying ecosystem goods and services according to beneficiaries and allows for comparison of ecosystem goods and services across geographies and scales. This tool is a large step forward towards answering many of the research needs identified in this report and will be a resource for researchers and modelers to develop more consistent EGS quantification tools that can scale up or down depending upon whether the decision is to be made at the neighborhood, municipal, regional, or state scale. A parallel framework called the National Ecosystem Services Classification System (NESCS) is being developed to connect final EGS to human welfare through cost-benefit, cost-effectiveness, and distribution analyses.

- **An Ecological Production Function Library** is in development by SHC Task 2.1.2.1. EGS production functions are essential to geographically specific decision making tools that value environmental benefits from various land uses. Consequently, this effort is a key input for community decision support tools. This product will be a resource for researchers and modelers to develop tools that quantify the ecosystem services benefits and losses expected from various land use decisions. The database is expected to be fully available online in March, 2015.

- **A Primer of Scaling Approaches and Analyses Useful in Ecosystem Management** was produced by SHC Task 2.1.2.4. While it is focused on resource management and doesn't address land use specifically, it may be useful for modelers and statisticians who must deal with variations in scale. Moreover the task includes ongoing work measuring ecosystem production and benefit functions. This work is very important to inform the development of decision making tools that can estimate the impact on ecosystem goods and services in response to land conversion.

- **A database of sustainability indicators and indices (DOSII)** is being produced by SHC Task 1.2.2.1. Land use is one of the community scale indicator categories covered in the database. This database will be a valuable resource for researchers, sustainability index developers, modelers, and sophisticated municipal planning offices looking to define their own benchmarks and characterize land use trends in sustainability.

- **A comparative analysis of community typologies** is being developed within SHC Task 2.1.2.2 to guide decision analysis approaches for sustainability. Different communities face different challenges for achieving sustainability. These challenges reflect the interplay between the geographic, environmental, social, and economic factors that help distinguish different places, and which contribute to the relative sustainability of a particular place. The typologies task seeks to build a basic classification methodology for community sustainability using statistical analysis of national-level datasets (Phase 1), which will then be refined in more focused collaborative work with Regional offices and a suite of pilot communities (Phase 2). The aim is to create a meaningful representation of different sustainability trajectories linked to key community characteristics, capabilities, policies and programs, and stressors. This product will ensure that decision tools developed in ORD for community sustainability will take a systems-based perspective that is adaptable and responsive to different decision contexts.

- **The Report on the Environment,** released every 4 years by SHC Project 3.4.1, describes recent trends in land use and land cover and tracks changes in 85 land use and land condition indicators including land cover of various types, ecological condition of undeveloped land and developed land relative to population change. It is a valuable resource for researchers, land use planners, natural resource managers and policy makers to refer to for recent national trends in land use, land cover, and ecological functioning. The list of indicators used to track these trends may be useful to modelers and sustainability index developers looking for standard metrics with solid data sources.

- **An Environmental Quality Index (EQI)** for all U.S. counties is being developed in SHC Task 1.2.2.3 that will combine measures in five domains: air, land, water, built environment, and sociodemographic (Lobdell, Jagai, Rappazzo, & Messer, 2011). The index will be expanded for use at smaller scales including the city and neighborhood scale, and eventually will be merged with the Human Well Being Index described below to create a comprehensive picture of the interaction of the environment, human health, and welfare.

- **A Human Well Being Index (HWBI)** is being developed in SHC Task 1.2.2.2 to characterize the flow of services that contribute to economic, social, and environmental well being. Modifications of the index will be made for specific needs, indluding a tribal well-being index and an index of social equity. The indices feed a visualization tool that will use community prioritization of values as an input to help community decision-makers and stakeholders better understand how decisions could potentially affect different aspects of well-being using. The final index is expected to be released near the end of 2014.

- **Common sustainability metrics and are catalogued** in a report that ranks the 50 most populous cities in US based upon these metrics (SHC Task 2.2.1.1). They conclude that the inclusion or exclusion of sustainability metrics has a large impact on the rank ordering of cities, over and above the health and environmental rankings alone. This product may be a useful resource not only for researchers and sustainability index developers, but also for community decision makers to make the case that tracking sustainability will improve local outcomes.

- **Image Analysis Support for Green Infrastructure Projects** is being conducted in SSWR Task 4.2B. The research uses LIDAR to develop a methodology that more accurately estimates percent impervious cover. Preliminary analyses have indicated that biotic communities are impacted at much lower levels of watershed imperviousness than previously thought. It is likely that 30-meter resolution National Land cover Data is underestimating impervious surfaces, particularly in suburban areas where tree cover and vegetation can mask it. This research will improve classification accuracy and allow better estimates of threshold levels of impervious surfaces for biotic integrity in urban and suburban riparian zones.

Geographically specific metrics and indicators are of particular use to communities, for an abundance of purposes, including to help identify and prioritize areas of particular concern and to understand the geographic context of decisions.

- **EnviroAtlas,** in SHC Project 1.2.3, is a GIS tool called the, which maps geography, demographics, and the production of ecosystem services, including toxins removed through tree coverage, ecosystems contributing to water quality, carbon sequestration, impervious surfaces, habitat, ecosystems that support food and fiber production, ecosystems which help mitigate natural disaster, and prevalence of recreational ecosystems. Future releases plan to include more information such as built environment measures, transportation, waste, and urban land use. These data are then combined with measured data and models to estimate condition and value of these resources. The Atlas is intuitively designed and does not require expertise to navigate its basic functions, therefore it is a resource for a wide variety of users, including local decision makers, natural resource managers, public health professionals, and more. This SHC tool begins to answer the call from some researcher for tools to map land use function, rather than just land use and cover (Verburg, et al., 2009). **The Urban Atlas**, a component of the EnviroAtlas project, is a GIS mapping tool called the Urban Atlas, which will initially cover 50 cities across the U.S. The tool will map the many ecosystem services including "temperature regulation, filtering of pollutants from the air, filtering of water, protections of quality and supply of drinking water, access to nature and open space, and potential for food production." In addition human health and well-being variables will be included to assess risks from heat waves, air pollution from traffic, flooding, algal blooms, contamination of drinking and recreational waters, and lack of opportunity for physical exercise, outdoor experience and play. This information can be overlaid with a variety of demographic variables, allowing detailed analysis of disproportionate exposure to identify possible local environmental justice issues.

6.2.3 Comparing Alternative Scenarios

With a growing population, dwindling land reserves, and distinct evidence for a variety of environmental, social, human health, and economic impacts that vary based on context, community decision makers have need of decision-support tools that allow comparison of multiple options based on local conditions.

- **The Integrated Climate and Land-Use Scenarios (ICLUS) Online** is an online mapping tool developed by ACE Task 137. The tool maps US population and housing density scenarios through 2100 to create estimates of impacts on climate and land use change scenarios. Scenarios and underlying data will be useful for regional planners, local governments, state agencies, non-profit organizations, and universities interested in long range local, statewide, regional or national analyses.

- **A dataset developed by ACE Task 155 takes regional land use patterns into account to downscale a model to show the regional effects of climate change**. The downscaled climate fields can then be used to predict the regional impacts of climate change on air quality and human health, water quality and availability, ecosystems, energy demand, and agriculture. Though this product is of indirect relevance to land use decision making, it is necessary to make global climate change models more relevant for regional land use decision makers.

- **An add-on tool to the USDA Water Erosion Prediction Project (WEPP) Tool**, developed by ACE, allows users to assess the sensitivity of soil erosion to climate change. This tool helps users identify the potential changes in soil erosion from a farm field in a particular location resulting from a range of plausible, mid 21st century changes in climatic conditions. It may be useful for watershed modelers, and as an input into more comprehensive models, to highlight how climate change may affect local land use concerns. However, its use is limited to specialists as it requires knowledge of the USDA WEPP model.

- **A Site-Based Stormwater Calculator**, produced by SSWR Task 7.1A is an online calculator that estimates amount and frequency of stormwater runoff from a specific site under a variety of land use scenarios. This tool is an online calculator that will estimate the annual amount and frequency of storm-water runoff from a specific site based on local soil conditions, land cover, and historical rainfall records. This can be simulated under a variety of land-use scenarios. Watershed modelers at the local and state level will find this a valuable tool to identify site-specific land use and green infrastructure improvements can prevent or reduce urban stormwater runoff and its consequences. http://www.epa.gov/research/waterscience/water-models-data-tools.htm

- **Guidance on municipal level best practices and a database on green infrastructure (GI) BMPs** are being developed by SSWR 4.2.A.3 and SHC 1.1.1.3. The product will provide: (1) a database of GI tools, resources, and associated benefits along with other attributes to aid users in finding tools/resources based on their decision context and needs (2) analysis of municipal characteristics and practices (nation-wide) that result in higher adoption of GI practices, and (3) a report synthesizing best practices and providing recommendations and methods for municipalities. This product will be direct use to community decision makers, property owners, developers, and more.

- **Advanced Subsurface Transport Modeling**. SHC project 3.1.5 is developing an advanced approach to subsurface contaminant transport modeling for the purpose of assessing potential impacts on drinking water wells due to population growth, natural cycles of wet and dry years and climate change. Multiple sources, types of sources and receptors can be included in the model, including a link with models for vapor intrusion. The model is intended as a management tool for assessing impacts to community water supplies and can be used in developing a source water protection plan.

- **A suite of decision support tools for communities** will be created in SHC Task 1.2.1.3. The goal is to develop tools that allow full value accounting that meet critical community level needs. This effort will fill a gap identified in this review for decision support tools that allow full cost and benefit accounting.

6.2.4 Collaborative Decision-Making

The local decisions that dictate the specific use of the land may favor development, resource extraction, or agricultural uses or they may emphasize protection and preservation. Either path may enhance the quality of lives of the citizens of the community, or they may result in degradation and loss of value and quality. Each parcel of land is unique and each community must balance land use decisions against the community's fundamental goals for development. In order to achieve this, the process for evaluating options and making decisions must be transparent, inclusive, and capable of evolving over time as priorities change. A long history of community planning has concluded that development and plans that have community buy in perform best. With increasingly diverse stakeholder groups, community decision makers need user friendly tools to help specialists, planners, community leaders, stakeholder groups, and citizens communicate well, prioritize issues, visualize alternatives, and explore solutions to achieve common goals.

- **DASEES (Decision Analysis for a Sustainable Environment, Economy, and Society),** in SHC Task 1.1.1.2, is a decision support tool .The tool is a stakeholder collaboration tool that guides users through a decision analysis framework to help participants build common understanding of complex problems and identify solutions. This tool helps communities collaboratively answer the questions "Which values are important to my community and what decisions help to reach those values?" It is intended to be adaptable to address specific sustainability issues that arise from the Theme 4 decision sectors. It is adaptable both in regards to the problems it analyzes and the scale of the issue, which are user defined. A prototype of the tool usable by experienced modelers will be available in September 2013, however, a user-friendly version that includes a menu of common decisions communities make should be available online near the end of 2014.

- **The C(ommunity)-Focused Exposure and Risk Screening Tool (C-FERST) and Tribal-FERST** is being developed in SHC Task 2.2.1.5. These web-based decision support tools are designed to help identify and prioritize local environmental issues. They are still in development however they have great relevance to land use. The tools allow users to: follow walk-through guidance and strategies for conducting community and tribal assessments; identify relevant local environmental issues; download information on these issues; map 5 exposures and risks; prioritize their community's issues; explore potential solutions; and link to other community-relevant tools including EPA/ORD's EnviroAtlas. T-FERST and C-FERST are emerging tools that will help decision makers identify environmental health issues in their communities, identify priorities in the context of limited resources and competing interests and address them effectively.

- **The Community Cumulative Assessment Tool (CCAT),** in SHC Task 2.2.3.5 walks users through the steps of an assessment process that integrates cumulative risk assessment (CRA) and Environmental Justice (EJ) concepts. The tool will help score and prioritize specific public health risks by location, including housing, playground, and school locations. It also explains uncertainties to lay users. This tool is a resource for community public health professionals and local decision-makers who are interested in tracking and addressing the environmental health issues and environmental justice concerns that may be present it their community, but are unsure of where to start.

- **A green infrastructure planning framework,** being developed by SSWR Task 4.1.A.1, aims to incorporate economic data and stakeholder and citizen preferences into the planning of green infrastructure in neighborhoods and communities. The classification framework will be applicable for communities nation-wide. It will be integrated with SHC work on decision analysis to provide a suite of tools for decision-making by communities. The framework and tools will show the benefits of implementing green infrastructure while meeting stakeholder goals. The final decision analysis tool will be populated for typical decision scenarios that can utilize GI solution.

For information on land use planning and decision support tools not produced within EPA's Office of Research and Development, please see Appendix B.

7 Research Needs to Address Community Land Use Sustainability

The research needs identified through the literature review can be summarized by several primary needs.

- **How do we best measure the impacts of land use choices?**
    - Some researchers advocate a change in focus from mapping land use and land cover, to mapping land function, including the ecosystem services derived from land. This will aid in studying the nonlinear relations between land use and land functions (Verburg et al, 2009).
    - What are the best indicators and metrics for park usage and physical activity rates?
    - Development of a standardized, universally accepted definition of sprawl could speed development of useful metrics for sprawl (E. H. Wilson, et al., 2003; Wolman, et al., 2005).

    - Although traffic-accident injuries and deaths among motor-vehicle occupants are often reported on a per-vehicle-mile-traveled basis, there is less consistency in how the risk of being in a traffic accident is reported for pedestrians and cyclists.
- **What are the thresholds of land use characteristics to achieve sustainable outcomes?**
    - What combination of density and compactness leads to the least overall energy consumption? Studies like Holden and Norland, 2005 are lacking in the U.S. context.
    - What is the highest residential density different consumer groups will tolerate?
    - What is the mix of density and transit necessary to avoid congestion in compact towns and cities?
    - Characterization of the density thresholds and magnitude for agglomeration benefits. The association between urban forest cover and improved air quality is primarily supported by models rather than experimental data (Cavanagh, et al., 2009). More experimental research is needed to identify the thresholds and conditions of urban forest cover to achieve air quality benefits.
    - What are the thresholds of preserved natural areas necessary to maintain biotic integrity? Though this has been done for forests, it would be very valuable to have analogous research conducted for other biomes and replicative studies to confirm initial findings.
    - Though habitat corridors have been shown to be a valuable tool in regional settings, only recently has there been empirical evidence that linking habitats in urban settings improves biodiversity (Ignatieva, et al., 2011). More research to identify connectivity thresholds and document the benefits of connectivity in an urban setting would be valuable.
    - How much intact urban forest is required to offset the impact of a given area of impervious surface (National Research Council, 2013)?
- **Quantify the impacts of land use decisions on the production of ecosystem goods and services**
    - A peer reviewed article, produced by SHC Task 2.1.4.4, reviewed the evidence for ecosystem services produced by the coastal wetlands of the Great Lakes including carbon sequestration, sport and commercial fish, retaining sediments and wild rice production. They find a research need very relevant to the topic of land conversion: to identify quantitative relationships between land use decisions and the delivery of ecosystem services (Sierszen, Morrice, Trebitz, & Hoffman, 2012)

  - What is the impact of compact, transit oriented development on exposure to air pollution?
  - Does impervious surface cover increase in response to increased walkability due to denser road network and wider streets to accommodate sidewalks?
  - What are the levels of water-related energy use in the commercial sector? (Kenway, et al., 2011)
  - Research is necessary to provides estimates of stormwater runoff, GHG emissions, and energy consumption specific to the United States.
  - What, in relation to urban form, are the required quantity, quality and configuration of urban green spaces to maintain, sustain and enhance ecosystem services and ecological function compatible with other functions? (James, et al., 2009)
  - How can the provision and management of fresh- water quantity and quality be promoted through urban green spaces? (James et al., 2009)
  - Quantify urban forest benefits to the point at which they can meet regulatory requirements for air and water pollution mitigation efforts (National Research Council, 2013).
- **Identify ideal levels for land use indicators**
  - To date, Transit-Oriented Development research has focused more on the policy tools that can be used to create them than on appropriate ways to design them or appropriate transportation mode shares to plan for (Jacobson & Forsyth, 2008).
  - What are the most appropriate ways to design Transit-Oriented Developments
  - What transportation mode shares in TODs are realistic to aim for given different contexts?
  - Define ideal guidelines, analogous to ideal body weight, for land use mix, walkability, proximity to greenspace, and more (A. L. Dannenberg, et al., 2003).
  - Improve predictive accuracy of land use change modeling
  - Modeling land use change (LUC) with accuracy is difficult. A review of 13 popular peer reviewed land use change modeling applications found that almost all (12), predicted more pixels inaccurately than accurately (Pontius et al, 2008). In order to be able to quantitatively compare alternative land use patterns, it is critical to be able to accurately model how intervention X changes land use. Poor model prediction limits the ability to assess the likely effectiveness of remedies. Therefore, advancing LUC modeling is a critical land use research need. A more complex modeling approach, such as the cellular automata referred to here, may provide different insights but does not necessarily improve accuracy over a simpler model.

- **Quantitatively compare alternative land use patterns**
    - Several reviewers have underscored the lack of consensus on the ideal urban form for sustainability, and in particular, a lack of theory to allow rigorous comparison of alternative urban forms (Jabareen, 2006; Tomita, Terashima, Hammad, & Hayashi, 2003).
    - Most studies to date that measure the impacts of urbanization on ecological systems use simple measures such as population density or percent impervious surface. This leaves a critical gaps in the science; as Alberti identifies, we do not know the specific effects of "different urban forms, densities, land use mix, and alternative infrastructures" nor the differential effects of "clustered versus dispersed and monocentric versus polycentric urban structures" (M. Alberti, 2010)..
    - Various social equity variables have been associated with density and compactness. However the most recent literature review in 2000 found weak evidence to support a positive connection between density and better access to public services and green space, and ambiguous evidence for increased access to jobs (Burton, 2000). Since this study was conducted in 2000, an updated review of the literature would be very valuable, particularly if it can identify density tipping points in the literature.
    - How do large preserved areas impact land use patterns in developed areas? Is their siting likely to cause leapfrog development styles or increased commute times?
    - What is the magnitude of the tradeoff between elevated local emissions and reduced regional emissions due to compact versus dispersed development, and to what degree can it be mitigated through green infrastructure?
    - Impervious surfaces must be measured on a per capita basis, rather than a per unit area basis to evaluate the impact of compact development on impervious surfaces. However research explicitly comparing the impervious surface loads of compact versus dispersed regions is lacking.
    - Cost of community service studies categorize land uses into discreet categories, and therefore have yet to address a mix of uses. There is a need for studies that address the revenues, infrastructure, and community service costs of mixed-uses.
    - Research to understand the differential ecosystem-level effects of alternative road networks (Coffin, 2007).
    - Though rural residential clustering is promoted as a smart growth strategy suited to the rural context, relatively little peer reviewed research exists comparing its impacts to alternative forms. Particularly, is residential clustering able to reduce exposure to pollutants such as pesticides and other agricultural runoff?

  - Compact development concentrates higher PTIA over a smaller area, which may reduce the region wide levels of impervious surfaces, but may allow very high impervious surface cover in very populated areas. Research to quantify the advantages and disadvantages inherent in this tradeoff would be a valuable contribution to the literature.
- **Provide decision support tools to allow full cost and benefit accounting**
  - Civic balance sheets that incorporate co-benefits of community goods, such as parks, so that they are quantitatively shown as valuable assets rather than fiscal liabilities. This enables resources to be allocated appropriately according to the public benefits received (Lambert, 2007). However achieving this goal is often beyond the means of community governments. Tools are needed which allow estimates of full costs and benefits for a variety of land use options.
- **Provide decision support tools to predict how land use changes will affect growth and development pattern**
  - Tools to help community planners achieving a balance between incentivizing compact development and preventing leapfrog development
  - Models to understand and predict the "interactions between road network structures and landscapes" (Coffin, 2007)
- **Provide user friendly decision support tools**
  - User friendly tools for quick integration into the planning process "Many of the tools available to communities to support decision-making processes are complex and powerful…But in many of the case studies reviewed in this report, we found that the tools had such steep learning curves that their actual utility in planning processes was limited, and while tools with different functions and purposes are often interoperable this added yet another layer of complexity (Smith & Snyder, 2011)."
- **Which practices best offset unintended consequences of land use patterns?**
  - Given that a compact land use pattern minimizes land consumption and air pollution on a regional level, how can planners best offset the increased local emissions and water pollution caused by density? (A. L. Dannenberg, et al., 2003)
- **How do land use practices influence human behavior?**
  - What is the mechanism by which greening vacant land reduces gun violence? Though the two are negatively correlated, it is not clear if the association is due to removing a former weapon storage location for criminals, or if improving the neighborhood aesthetic denormalizes criminal behavior (frequently referred to as the broken windows theory), or due to another explanation entirely.

  - The effects of the built environment on walking and cycling (rather than on motorized modes of transportation, which have been studied significantly more) (Robert Cervero & Duncan, 2003).
  - How are people's travel behaviors affected by land-use patterns around the work end of their commute trips, as opposed to around the home end? Research on this topic would alleviate the uncertainty about the implications of working in a TOD rather than living in one. However, it can be said that if someone makes extra stops in between home and work that are not very close to either their home or their work, the land-use patterns surrounding those extra stops are unlikely to affect the mode choice for the overall tour (L. Frank, et al., 2008a).
  - What is the weight of these elements in determining the use of green space: proximity, acreage, accessibility, quality, amenities, resources, perceived neighborhood safety?
  - Are physical environment measures or perceptions of the environment more important to levels of physical activity? (A. L. Dannenberg, et al., 2003)
  - Self-selection does not entirely explain the positive relationship between park space availability and physical activity. "Future prospective and intervention studies are needed to draw more definitive conclusions about causality." (Kaczynski & Mowen, 2011).
- **How do land use practices impact disadvantaged or underrepresented populations?**
  - What are the differential effects of parks and greenspace on those who are less fit or with health conditions, women, children, and seniors? Bowler et al 2010 notes in a meta-analysis of studies on the health effects of natural environments that most studies were conducted on fit college-aged men who volunteered.
  - What are the effects of longer-term exposure to parks and the effects of particular contexts (e.g. post-surgery or completing certain activities)? Furthermore, outcomes that appear unaffected pre and post-test have been shown to vary if measured during exposure, e.g. blood pressure drops during exposure to natural environments, but does not persist afterwards (Bowler, et al., 2010).
  - What techniques support affordable housing in accessible locations? (C. Dawkins, Schilling, & Alfonzo, 2011)
  - How does place of residence impact the efficacy of routine healthcare? (Corburn, 2013)
  - Research to determine if and when agricultural conservation policies raise property values sufficiently to displace low socio-economic residents (Poor & Brule, 2007).

- The accessibility of state and national parks may vary by groups, and in particular be less accessible to low socioeconomic groups. One study found that "my financial situation" was the second most commonly cited constraint to visiting undeveloped natural areas (UNAs) (39%) after "my family and friends do not visit UNAs" at 42% (Chavez, et al., 2008). More research may be needed to identify the best strategies to provide travel accessibility of natural areas to all groups.
- More research is necessary to examine how exposure is spatially determined. This would be very valuable for city planners to making zoning and siting decisions to minimize health effects from the high-risk industrial land uses.
- Does smart growth mainly benefit high SES individuals? (Dannenberg et al, 2003)
- What benefits does the creation of urban green space provide in areas that have poor environmental conditions or social problems? (James et al, 2009)
- How do the following processes contribute to and create environmental inequalities among certain populations and communities: suburbanization, land use planning, residential segregation, exclusionary zoning, banking systems (mortgage guarantees), transportation policies, housing policies, property speculation?
- What is the role of systemic economic inequalities, uneven regional development in creating and or maintaining inequalities in environmental health and distribution of environmental hazards and environmental quality?
- How are the benefits of urban forestry distributed across socioeconomic divides (National Research Council, 2013)?

- **How do land use policies and practices impact human well being :**
  - Evaluation of the effectiveness of mixed income housing projects in improving resident well-being (L. M. Anderson, et al., 2003).
  - Does having a mix of housing types ease the disadvantages of economic inequality?
  - How do single neighborhood characteristics influence mental health (rather than neighborhood types encompassing panoply of characteristics)?
  - More research is needed, however, on which strategies for dealing with vacant lots provide the best outcomes within various contexts.
- **How do land use policies and practices impact the market and the private sector?**
  - It would be beneficial to have more research on the effect of market imperfections on roads. A market imperfection is anything that causes the market price of a good or service to differ either from the cost of supplying it or from the value placed on it by the customer. Market imperfections may result either from government policies or from efforts by private-sector

actors to maximize their profits. For example, land use regulations produce market imperfections by constraining the reaction of the real estate market to the presence of a new, expanded, or altered roadway. Meanwhile, if an inadequate or inefficient roadway system causes a given customer base to only have easy access to one or a small number of businesses that provide a given type of product or service, the business or businesses in question will be able to exert a certain amount of monopoly- or oligopoly-type power, allowing them to set the prices of their products and services higher than the cost of providing them, which is another type of market imperfection (Hof, et al., 2012).

- Not much research has yet been done on when the "announcement effect" occurs. This is the phenomenon wherein the anticipation of benefits from a new road or other piece of infrastructure causes nearby land prices to increase prior to the beginning of construction (Tsutsumi & Seya, 2008).
- Past research has encountered difficulty in the task of separating out the economic effects of road usage from those of other parts of the local economy, such as labor and private capital. Furthermore, because different modes of transportation (both road-based and non-road-based) relieve each other's congestion effects, their economic impacts are difficult to separate from one another (Kennedy, 2002).
- There is evidence that areas with smart growth controls in place may generate more construction jobs, however few studies have corroborated this.
- Do agricultural conservation policies raise property values sufficiently to displace low socio-economic residents? (Poor & Brule, 2007)

8 Linkages for Land Use across Federal Agencies

EPA's primary inter-governmental effort on land use is through the Housing and Urban Development (HUD) – Department of Transportation (DOT) – Environmental Protection Agency (EPA) Partnership for Sustainable Communities (C. Dawkins, et al., 2011). The Partnership for Sustainable Communities was developed in 2009 to help communities improve access to affordable housing and transportation while protecting the environment. The partnership works to coordinate federal housing, transportation, water, and other infrastructure investments to make neighborhoods more prosperous, allow people to live closer to jobs, save households' time and money, and reduce pollution. There are six principles of livability that HUD, DOT and EPA incorporate into federal funding programs, policies, and future legislative proposals:

- Provide more transportation choices: Develop safe, reliable, and economical transportation choices to decrease household transportation costs, reduce our nation's dependence on foreign oil, improve air quality, reduce greenhouse gas emissions, and promote public health.

- Promote equitable, affordable housing: Expand location- and energy-efficient housing choices for people of all ages, incomes, races, and ethnicities to increase mobility and lower the combined cost of housing and transportation.
- Enhance economic competitiveness: Improve economic competitiveness through reliable and timely access to employment centers, educational opportunities, services and other basic needs by workers, as well as expanded business access to markets.
- Support existing communities: Target federal funding toward existing communities—through strategies like transit-oriented, mixed-use development and land recycling—to increase community revitalization and the efficiency of public works investments and safeguard rural landscapes.
- Coordinate and leverage federal policies and investment: Align federal policies and funding to remove barriers to collaboration, leverage funding, and increase the accountability and effectiveness of all levels of government to plan for future growth, including making smart energy choices such as locally generated renewable energy.
- Value communities and neighborhoods: Enhance the unique characteristics of all communities by investing in healthy, safe, and walkable neighborhoods—rural, urban, or suburban

"…by working together, these agencies can make sure that when it comes to development -- housing, transportation, energy efficiency -- these things aren't mutually exclusive; they go hand in hand. And that means making sure that affordable housing exists in close proximity to jobs and transportation. That means encouraging shorter travel times and lower travel costs. It means safer, greener, more livable communities."

-- President Barack Obama, July 13, 2009

EPA has also partnered with other federal agencies to address specific areas of overlap in the realm of land use and sustainability. For example:

EPA and FEMA partner to help communities prepare for and recover from natural disasters: The two agencies will collaborate to help communities that have been hit by disasters to rebuild in ways that protect the environment, create long-term economic prosperity, and enhance neighborhoods. FEMA and EPA will also help communities incorporate into hazard mitigation plans strategies that will improve quality of life and direct development away from vulnerable areas. http://www.epa.gov/smartgrowth/fema_moa.htm

EPA and NOAA partner to help coastal communities: Under the agreement, the two agencies will partner with local communities and other governmental entities to give waterfront communities the tools and resources they need to grow in ways that benefit the economy, public health, and the environment while protecting coastal ecosystems, including anticipating and reducing the impacts of climate change. http://www.epa.gov/smartgrowth/noaamoa.html

9 CONCLUSIONS

Decisions regarding how land is used are among the most critical choices a community can make that directly impact the quality of life. Land is needed to feed, to house, and to provide resources that drive the economic development of society. While water and air are transient, land is not.

The discourse on achieving sustainability for our society should be consistent with the goal of well-being and quality of life for all members of the society while maintaining life sustaining ecosystem goods and services. Land use has been shown to be critical to this end. Changes in land use significantly impact the environment, the economy, and social conditions. Furthermore, land use change is usually very long-lasting. Strides have been made to reduce the detrimental and long lasting effects of land use change; however land continues to be development and fragmented resulting in the reduction of the benefits and degradation of its functionality. The question arises, which land use practices are sustainable over time?

An overriding theme which has emerged from this literature review is that for many measures of sustainability, development form and pattern matter more than just development intensity or density. For example, encouraging walking and bicycling and the attendant benefits of these alternative transportation modes, small blocks and safe neighborhoods are more important than density. Use of green infrastructure wherever possible improves water quality, reduces wastewater treatment costs, and affects human well being through a variety of processes. A dispersed land use pattern, as measured through a sprawl index, by definition, cannot be sustained indefinitely due to the need for constant infusion of new rural areas for development. The associated negative health and environmental issues described above, which accompany sprawl, additionally detract from the use of this development form.

Certainly some land use patterns do have minimum density thresholds to be effective. For example, transit-oriented development requires a very minimum of 10 households per acre for consistent bus service, and around 30 households per acre for rail. Certain land use patterns also lend themselves to more or less density. However the literature is shifting towards an understanding that associations with density are an imprecise proxy for land use pattern, rather than the driving force.

Compact development is a key example of this principle. It can be measured in a variety of ways and is typically considered a combination of various elements including density, centralization, street connectivity, a mix of uses, and contiguous development. However it is not merely density. Los Angeles, a very dispersed city, is also very dense. On the other hand, many rural New England villages are compact, but still at rural densities. By a number of measures, it is more sustainable than dispersed development. For example, compact development preserves open space and agricultural land, promotes less driving and more walking for transportation (which in turn improves air quality and human health), leads to lower per capita GHG emissions, supports more social contact and other measures of social capital, and leads to lower infrastructure capital and maintenance costs.

Nonetheless, our knowledge of the impact of various urban forms is still in its infancy. As Alberti (2010) emphasizes, we do not yet know “how clustered versus dispersed and monocentric versus polycentric urban structures differently affect ecological conditions. Nor do we understand the ecological tradeoffs associated with different housing or alternative infrastructures.” The cutting edge of research now, therefore, is to define standard methods for measuring land use patterns and teasing out their exact links to important outcomes.

ORD is already in the process of developing valuable tools and research that can address issues of quantification, forecasting, planning, tradeoffs, and collaborative decision making. As you can see in table xxx, ORD has a substantial number of products addressing research questions about the quantification of ecosystem goods and services, measuring sustainability, comparing land use patterns, and providing user friendly decision support tools.

In particular, ORD’s Sustainable and Healthy Communities program is in the process of developing and delivering very useful decision support tools. While best practices can influence the direction of land use activities, decision support tools provide a solid foundation for the social, environmental and economic considerations of multiple approaches. ORD has invested heavily in advancing the field of ecosystem services valuation, which has provided critical environmental information for development of new decision support tools. Indeed, much of the strength of the Sustainable and Healthy Communities program in contributing to land use research needs is in the area of decision support tools. While ORD may not be focusing on individual facets of land use research, it plays a vital role in compilation of such information and communication to communities. For example, tools such as DASEES and C/T-FERST directly answer the call for user friendly decision support tools that don’t have steep data and expertise requirements (Smith and Snyder, 2011).

Table 4 ORD Products and Research Needs

ORD Products and Research Needs

How do we best measure the impacts of land use choices?
Final Ecosystem Goods and Services Classification System (FEGS-CS). SHC Task 2.1.1.1 A Primer of Scaling Approaches and Analyses Useful in Ecosystem Management. SHC Task 2.1.2.4. Common sustainability metrics and are catalogued in a report that ranks the 50 most populous cities in US based upon these metrics (SHC Task 2.2.1.1). A database of sustainability indicators and indices (DOSII). 1.2.2.1. The Report on the Environment. SHC Project 3.4.1.
What are the thresholds of land use characteristics to achieve sustainable outcomes?
No products identified
Identify ideal levels for land use indicators
No products identified
Quantify the impacts of land use decisions on the production of ecosystem goods and services
A report titled Neighborhood Scale Quantification of Ecosystem Goods and Services. SHC Task 2.1.4.1. EnviroAtlas and the Urban Atlas. SHC Project 1.2.3 An Ecological Production Function Library. SHC Task 2.1.2.1. Several peer-reviewed publications that quantify, value, and estimate the production of ecosystem goods and services from Tampa Bay coastal areas. SHC Task 2.1.4.1. A publication on the effects of urbanization on migrating birds on the western shore of Lake Michigan. SHC Task ? A peer reviewed report of selected ecosystem services provided by coastal wetlands of the Laurentian Great Lakes. SHC Task 2.1.4.4.
Quantitatively compare alternative land use patterns
A dataset that shows the regional effects of climate change. ACE Task 155 An add-on tool to the USDA Water Erosion Prediction Project (WEPP) Tool. ACE A Site-Based Stormwater Calculator. SSWR Task 7.1A
Improve predictive accuracy of land use change modeling
No products identified
Decision support tools to predict how land use changes will affect growth and development pattern
The Integrated Climate and Land-Use Scenarios (ICLUS) Online. ACE Task 137
Provide user friendly decision support tools
DASEES (Decision Analysis for a Sustainable Environment, Economy, and Society). SHC Task 1.1.1.2 The C(ommunity)-Focused Exposure and Risk Screening Tool (C-FERST) and Tribal-FERST. SHC Task 2.2.1.5. The Community Cumulative Assessment Tool (CCAT). SHC Task 2.2.3.5
Decision support tools to allow full cost and benefit accounting

A suite of decision support tools for communities that allow full value accounting. SHC Task 1.2.1.3.	
Which practices best offset unintended consequences of land use patterns?	
A report on sparrow counts in Rhode Island. SHC Task 2.1.4.3 Guidance on municipal level best practices and a database on green infrastructure (GI) BMPs. SSWR 4.2.A.3 and SHC 1.1.1.3. A green infrastructure planning framework. SSWR Task 4.1.A.1	
How do land use policies and practices impact human well being? How do land use practices impact disadvantaged or underrepresented populations?	
A collection of 15 papers on disproportionate health risks. Task 2.2.3.5	
How do land use practices influence human behavior?	
No products identified	
How do land use policies and practices impact the market and the private sector?	
No products identified	

10 Recommendations for EPA/ORD Science to Advance Land Use Practices for Sustainability

However research needs remain that ORD can address. As you can see in table xxx, there are several categories of land use sustainability needs that SHC is not yet addressing. Of these, there are three categories in which EPA has particular expertise:

1. What are the thresholds of land use characteristics to achieve sustainable outcomes?
2. Improve the predictive accuracy of land use change modeling
3. Provide decision support tools to allow full cost and benefit accounting

In addition, specific research needs identified in other categories provide opportunities for future ORD research relevant to critical land use issues. Identified below are the primary research needs identified through this review which EPA has the expertise to address, but has not yet emphasized.

- **What are the thresholds of land use characteristics to achieve sustainable outcomes?**
    - What combination of density and compactness leads to the least overall energy consumption? Studies like Holden and Norland, 2005 are lacking in the U.S. context.
    - What are the thresholds of preserved natural areas necessary to maintain biotic integrity? Though this has been done for forests, it would be very valuable to have analogous research conducted for other biomes.

  - More research to identify connectivity thresholds and document the benefits of connectivity in an urban setting would be valuable (Ignatieva et al, 2011).
  - How much intact urban forest is required to offset the impact of a given area of impervious surface (National Research Council, 2013)?
- **Quantify the impacts of land use decisions on the production of ecosystem goods and services**
  - Does impervious surface cover increase in response to increased walkability due to denser road network and wider streets to accommodate sidewalks?
  - What, in relation to urban form, are the required quantity, quality and configuration of urban green spaces to maintain, sustain and enhance ecosystem services and ecological function compatible with other functions? (James et al, 2009)
  - How can the provision and management of fresh- water quantity and quality be promoted through urban green spaces? (James et al., 2009)
  - Quantify urban forest benefits to the point at which they can meet regulatory requirements for air and water pollution mitigation efforts (National Research Council, 2013).
- **Identify ideal levels for land use indicators**
  - Define ideal guidelines, analogous to ideal body weight, for land use mix, walkability, proximity to greenspace, and more. (Dannenberg et al, 2003)
  - Improve predictive accuracy of land use change modeling
  - Advancing LUC modeling is a critical land use research need. In order to be able to quantitatively compare alternative land use patterns, it is critical to be able to accurately model how intervention X changes land use.
- **Quantitatively compare alternative land use patterns**
  - How do "clustered versus dispersed and monocentric versus polycentric urban structures differently affect ecological conditions" (Alberti, 2010)?
  - What is the magnitude of the tradeoff between elevated local emissions and reduced regional emissions due to compact versus dispersed development, and to what degree can it be mitigated through green infrastructure?
  - Research to compare the per capita impervious surface loads of compact versus dispersed regions.
  - Research to understand the differential ecosystem-level effects of alternative road networks (Coffin, 2007).
  - Is residential clustering able to reduce exposure to pollutants such as pesticides and other agricultural runoff?
- **Decision support tools to allow full cost and benefit accounting**
  - Tools are needed which allow estimates of full costs and benefits for a variety of land use options, such as parks, and allows benefits beyond financial ones to be quantified. Economic considerations are often of

foremost importance to communities struggling with budget deficits, unemployment, and inequality. In many cases, including green infrastructure, mixed uses, and compact development, environmental sustainability is complementary to economic sustainability. However tools are necessary to allow communities to determine if this is the case for their circumstances.
    - Decision support tools to predict how land use changes will affect growth and development pattern
    - Models are needed to understand and predict the "interactions between road network structures and landscapes" (Coffin, 2007)
- **Which practices best offset unintended consequences of land use patterns?**
    - Given that a compact land use pattern minimizes land consumption and air pollution on a regional level, how can planners best offset the increased local emissions and water pollution caused by density? (Dannenberg et al, 2003)
- **How do land use practices impact disadvantaged or underrepresented populations?**
    - What are the differential effects of parks and greenspace on less studied populations, including those who are less fit or with health conditions, women, children, and seniors?
    - What are the effects of longer-term exposure to parks and the effects of particular contexts (e.g. post-surgery or completing certain activities)?
    - How does place of residence impact the efficacy of routine healthcare? (Corburn, 2009)
    - More research is necessary to examine how exposure is spatially determined. This would be very valuable for city planners to making zoning and siting decisions to minimize health effects from the high-risk industrial land uses.
    - Does smart growth mainly benefit high SES individuals? (Dannenberg et al, 2003)? While the principles of smart growth support equity, diversity, and affordable housing, in practice, developments may inadvertently exclude the poor. Smart growth or new urbanist style redevelopment may introduce many positive changes, however it may also displace or exclude poorer residents by increasing property values, failing to provide affordable housing, or creating exclusionary privately owned 'public spaces' such as outdoor malls and plazas.
    - What benefits does the creation of urban green space provide in areas that have poor environmental conditions or social problems? (James et al, 2009)
    - How do the following processes contribute to and create environmental inequalities among certain populations and communities: suburbanization, land use planning, residential segregation, exclusionary zoning, banking systems (mortgage guarantees), transportation policies, housing policies, property speculation?

- What is the role of systemic economic inequalities, uneven regional development in creating and or maintaining inequalities in environmental health and distribution of environmental hazards and environmental quality?
- How are the benefits of urban forestry distributed across socioeconomic divides (National Research Council, 2013)?

Appendix A FEDERAL AUTHORITIES RELEVANT TO LAND USE

Federal agencies have a significant number of programs and authorities relevant to land use, land use planning, and decision making at the community level. While a listing of all of the relevant programs would not be practical, we have compiled a list of the most relevant laws and regulations in the table below. We list for which agencies they apply, and provide a short description of their purpose.

<table>
<tr><th colspan="2">Federal Authorities Relevant to Land Use</th></tr>
<tr><td colspan="2">Environmental Protection Agency (EPA)</td></tr>
<tr><td>LAWS</td><td>REGULATIONS</td></tr>
<tr><td>National Environmental Policy Act of 1970-42 USC 4321 et seq.
All Federal agencies required to consider the environmental impact of actions via an Environmental Impact Assessment. Public action and explanations are required for each decision. In section 309 of the Clean Air Act, EPA is required to review all environmental impact statements from Federal agencies and refer unsatisfactory reviews to the Council of Environmental Quality. EPA is responsible for the administrative duties of the Environmental Impact Statement filing process.</td><td>40 CFR 1508.27 Requires all Federal agencies, except the Executive Branch, to prepare environmental assessments and environmental impact statements if necessary. The environmental impact statement identifies the action and how it may impact the environment (“terrestrial ,aquatic, subterranean, and aerial environments, such as islands, cities, rivers or parts thereof”)
30-50-60 Environmental impact statement requirement</td></tr>
<tr><td colspan="2">Clean Air Act (CAA) 42 USC 7401 et seq (1970)
Amendments 1977, 1990
EPA regulates air emissions from stationary and mobile sources. The law establishes ambient air quality standards for the Nation (National Ambient Air Quality Standards) In addition, EPA regulates hazardous air pollutants (section 112)

Clean Water Act (CWA) 33 USC 1251 et seq (1972) - Significant expansion of the Federal Water Pollution Control Act of 1948. Regulates discharge of pollutants into surface waters of the U.S.; Sets pollution, contaminant and wastewater standards for States and Industry

Safe Drinking Water Act (SDWA) 42 USC 300 et seq (1974)
Amendments 1996-EPA must consider risk and cost assessment. The amendment requires the best available Peer-reviewed science to be used when setting the standards. In addition, the SDWA protects underground sources of drinking water.

Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980 42 USC 9601 et seq-Congress established the “Superfund” as a source of monies dedicated to the cleanup of land that has been contaminated by hazardous spills, leaks and disasters by</td></tr>
</table>

<table>
<tr><td colspan="2">unidentified parties. EPA enforces through penalties.

Superfund Amendments and Reauthorization Act (SARA) of 1986-Congress authorized EPA to continue CERCLA with site specific amendments, additional monies, and enforcement; section III includes emergency planning and Community Right to Know amendment

Small Business Liability Relief and Brownfields Revitalization Act of 2002 (Brownfields Law)-amendments to CERCLA provide funds to assess and cleanup Brownfields

Resource Conservation and Recovery Act of 1976 (RCRA) 42 USC seq 1976-EPA authorized to monitor and ensure compliance of hazardous waste from the site of contamination, to hazardous waste cleanup, to storage “cradle to grave”</td></tr>
<tr><td colspan="2">Housing and Urban Development (HUD)</td></tr>
<tr><td>Fair Housing Act of 1968-Prohibits discrimination in the sale rental and financing of dwellings and in other house-related transactions based on race, color, national origin, religion, sex, familial status and disability.

Housing and Community Development Act of 1974 Title 42- Grantees determine the type of community development projects that will be funded instead of the Federal government.</td><td>The Public Health and Welfare chapter 69
Community development sec. 5318
Urban development sec. 5319
Community participation sec. 5319</td></tr>
<tr><td colspan="2">Office of Surface Mining Reclamation and Enforcement (OSM)</td></tr>
<tr><td>Surface Mining Control and Reclamation Act of 1977 USC Title 30, chapter 25-The Agency is responsible for reclaiming abandoned mine lands. Costs are attached to coal and removal and the monies are placed into trust for clean-up purposes. The law establishes environmental standards for mining companies. Title IV-fee collection and distribution of monies in grants to states and tribes; Title V-regulates coal mining on Federal lands</td><td>30 CFR –Mineral resources, Chapter VII (SMCRA) Parts 700-955</td></tr>
</table>

Federal Authorities Relevant to Land Use	
United States Department of Agriculture (USDA)	
LAWS	REGULATIONS
Farmland Protection Policy Act of 1994 (FPPA)- This act requires Federal agencies to minimize the impact of programs which convert farmland to nonagricultural use.	7 CFR 658 Farmland Protection
Bureau of Land Management (BLM)	
Public Law 94-579 1976-Guidelines for management, development, protection and enhancement of Public lands *Federal Land Policy and Management Act of 1976 sec. 103* Title II-The law establishes the Bureau of Land Management. The BLM is authorized to manage land use planning, land acquisition, disposition and development. Title II specifies community development regulations.	
United States Bureau of Reclamation (USBR)	
Reclamation Act of 1902-Development of irrigation and hydropower projects in 17 Western States *Town Sites and Power Development Act of 1906*-authority to Secretary of the Interior to lease surplus power or power privileges *Federal Water Power Act of 1920*-regulated hydroelectric development of navigable waterways *Reclamation Project Act 1939*-extended the contract term to 40 years for sale of power or lease of power privileges, gives preference to public entities *Flood Control Act of 1944*-authorized the Secretary of the Interior to market power from Army Corps of Engineers projects	43 CFR Part 402-Sale of land in Federal Reclamation Projects 43 CFR Part 414-Offstream storage of Colorado River water and development and release of Intentionally Created Unused Apportionment in the lower Division States 43 CFR Part 422-Law enforcement authority at bureau of Reclamation projects 43 CFR Part 420-Off-Road vehicle use 43 CFR Part 423,429-Public conduct on Bureau of Reclamation Facilities, lands and water bodies 43 CFR Part 426-limits the acreage the Federal government can reclaim; Rules and regulations 43 CFR Part 428-Information requirements for certain Farm operations in excess of 900 acres and the eligibility of certain formerly excess land

EPA,BLM,HUD	
Clean Water Act (CWA) 33 USC 1251 et seq (1972) - Significant expansion of the Federal Water Pollution Control Act of 1948. Regulates discharge of pollutants into surface waters of the U.S.; Sets pollution, contaminant and wastewater standards for States and Industry Safe Drinking Water Act (SDWA) 42 USC 300 et seq 1974 Amendments 1996-Risk and cost assessment required; The amendment requires the best available Peer-reviewed science to be used when setting the standards. The SDWA protects underground sources of drinking water. Comprehensive Environmental Response compensation and Liability Act (CERCLA) of 1980 42 USC 9601 et seq The "Superfund" is a source of monies dedicated to the cleanup of land contaminated by hazardous spills, leaks and disasters by unidentified parties. EPA is authorized to enforce CERCLA through penalties. Superfund Amendments and Reauthorization Act (SARA) of 1986 Congress authorized EPA to continue CERCLA with site specific amendments, additional monies, and enforcement; section III includes emergency planning and Community Right to Know amendment Small business liability Relief and Brownfields Revitalization Act of 2002 (Brownfields Law) amendments to CERCLA provide funds to assess and cleanup Brownfields Resource Conservation and Recovery Act of (RCRA) 42 USC seq 1976 EPA authorized to monitor and ensure compliance of hazardous waste from the site of contamination, to hazardous waste cleanup, to storage	40 CFR Parts 150-189

"cradle to grave" Federal Insecticide, Fungicide, and Rodenticide Compliance Monitoring (FIFRA) Act of 1972-Federal regulation of pesticide distribution, sale and use; all pesticides required to be registered Federal Land Policy and Management Act of 1976 sec. 103 Title II-(FPPA) This act requires Federal agencies to minimize the impact of programs which convert farmland to nonagricultural use. National Environmental Policy Act of 1969 All Federal agencies required to consider the environmental impact of actions via an Environmental Impact Assessment. Public action and explanations are required for each decision. In section 309 of the Clean Air Act, EPA is required to review all environmental impact statements from Federal agencies and refer unsatisfactory reviews to the Council of Environmental Quality. EPA is responsible for the administrative duties of the Environmental Impact Statement filing process.	40 CFR 1508.27 Requires all Federal agencies, except the Executive Branch, to prepare environmental assessments and environmental impact statements if necessary. The environmental impact statement identifies the action and how it may impact the environment ("terrestrial ,aquatic, subterranean, and aerial environments, such as islands, cities, rivers or parts thereof") 30-50-60 Environmental impact statement requirement
EPA,BLM,USDA,USBR	
Comprehensive Environmental Response compensation and Liability Act (CERCLA) of 1980 42 USC 9601 et seq The "Superfund" is a source of monies dedicated to the cleanup of land contaminated by hazardous spills, leaks and disasters by unidentified parties. EPA is authorized to enforce CERCLA through penalties. *Federal Land Policy and Management Act of 1976 sec. 103* Title II The law establishes the Bureau of Land Management. The BLM is authorized to manage land use planning, land acquisition, disposition	43 CFR Part 402-Sale of land in Federal Reclamation Projects 43 CFR Part 428-Information requirements for certain Farm operations in excess of 900 acres and the eligibility of certain formerly excess land

and development. Title II specifies community development regulations. Farmland Protection Policy Act of 1994 (FPPA) This act requires Federal agencies to minimize the impact of programs which convert farmland to nonagricultural use. Reclamation Act of 1902 Development of irrigation and hydropower projects in 17 Western States National Environmental Policy Act of 1969 All Federal agencies required to consider the environmental impact of actions via an Environmental Impact Assessment. Public action and explanations are required for each decision. In section 309 of the Clean Air Act, EPA is required to review all environmental impact statements from Federal agencies and refer unsatisfactory reviews to the Council of Environmental Quality. EPA is responsible for the administrative duties of the Environmental Impact Statement filing process.	40 CFR 1508.27 Requires all Federal agencies, except the Executive Branch, to prepare environmental assessments and environmental impact statements if necessary. The environmental impact statement identifies the action and how it may impact the environment ("terrestrial ,aquatic, subterranean, and aerial environments, such as islands, cities, rivers or parts thereof") 30-50-60 Environmental impact statement requirement
EPA,USBR,OSM	
Surface Mining Control and Reclamation Act of 1977 USC Title 30, chapter 25-The Agency is responsible for reclaiming abandoned mine lands. Costs are attached to coal and removal and the monies are placed into trust for clean-up purposes. The law establishes environmental standards for mining companies. Title IV-fee collection and distribution of monies in grants to states and tribes; Title V-regulates coal mining on Federal lands *Clean Water Act (CWA) 33 USC 1251 et seq (1972)* - Significant expansion of the Federal Water Pollution Control Act of 1948. Regulates discharge of pollutants into surface waters of the U.S.; Sets pollution, contaminant and wastewater standards for States and	

Industry Safe Drinking Water Act (SDWA) 42 USC 300 et seq 1974 Amendments 1996-Risk and cost assessment required; The amendment requires the best available Peer-reviewed science to be used when setting the standards. The SDWA protects underground sources of drinking water. Comprehensive Environmental Response compensation and Liability Act (CERCLA) of 1980 42 USC 9601 et seq The "Superfund" is a source of monies dedicated to the cleanup of land contaminated by hazardous spills, leaks and disasters by unidentified parties. EPA is authorized to enforce CERCLA through penalties Superfund Amendments and Reauthorization Act (SARA) of 1986 Congress authorized EPA to continue CERCLA with site specific amendments, additional monies, and enforcement; section III includes emergency planning and Community Right to Know amendment	
Reclamation Act of 1902 Development of irrigation and hydropower projects in 17 Western States	43 CFR Part 423,429-Public conduct on Bureau of Reclamation Facilities, lands and water bodies
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Tools to evaluate urban form:

- **A workplace walkability audit tool** has been developed to assess the walkability of worksites, the first to expand walkability tools from the neighborhood to the workplace (Dannenberg, Cramer, and Gibson, 2005). The validated tool can help planners and facility managers identify and eliminate barriers to walking in the workplace and improve employee health.
- **The WalkScore methodology** is used to assess neighborhood walkability based on objective GIS indicators (primarily the number and variety of amenities within a ¼ mile); several studies have confirmed the validity of its estimates, at least at 1600m scale (Duncan, 2011). Real estate agents have incorporated WalkScore into listings and estimate that a 10-point increase in the WalkScore increases the value of a property by 5-8% (Pivo, 2011). An important limitation to WalkScore is the inability to measure other important drivers of walking including crime, pedestrian safety, and attractiveness.
- **Neighborhood Environment Walkability Scale (NEWS)** is a 98-question tool used to assess perceived environmental attributes that influence physical activity. The NEWS tool has been validated and determined to be generalizable to urban locations across the United States. (Cerin et al, 2006)
- **ParkScore,** developed by The Trust for Public Land, ranks the 40 largest city parks based on acreage (median park size and acreage as percentage of city area); service & investment (spending-per-resident and playgrounds per-10,000-residents); plus access (percentage of the population living within a ten minute walk of a public park) (Harnik, Donahue, & Weiswerda, 2012; "Park Score Project,").
- **Community Park Audit Tool (CPAT)** assesses the potential of a park to promote physical activity . The tool includes measures of accessibility, amenities, quality, and safety (Kaczynski et al, 2012). The tool was developed and tested with community stakeholders in order to ensure it was meaningful and applicable to a diverse group.
- **Protocol for Assessing Community Excellence in Environmental Health (PACE EH)** is a tool to assess direct health consequences of community design decisions. The purpose of the PACE EH tool is similar to that of health impact assessments.
- **Models developed by the University of Connecticut** use satellite based land cover data to quantify changes in forest fragmentation, open space and urban growth (Civco, et al., 2002).

Tools to plan development:

- **Smart Location Database and Index.** This index identifies sustainable locations for new development by characterizing census block groups using five variables (i.e., the 5 Ds): density (population, housing, and jobs)s; diversity of land use; urban design;

destination accessibility, and distance to transit. https://metrocouncil.onlinegroups.net/groups/research/files/f/26322-2012-02-28T213936Z/SLD_v02_report.pdf

- **Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND)** sets standards for sustainable best practices of communities and provides certification to developments that meet those standards. It was developed in partnership with the Congress for the New Urbanism and the Natural Resources Defense Council. Elements of the built environment that limit the need for personal vehicles and support alternative transportation are emphasized. Key parameters include transportation options; a mix of uses; minimum impacts on the quality of air and water; access to parks and open space. http://www.usgbc.org/neighborhoods
- **Sustainable SITES Initiative (SSI)** is a rating system and reference guide that provides performance benchmarks for the design, construction, and maintenance of sustainable sites. This venture certifies landscapes, with or without buildings, for compliance with their benchmarks for sustainability. The US Green Building Council and future iterations of LEED will incorporate elements of the SSI rating system to expand the LEED concept to the landscape surrounding LEED buildings. http://www.sustainablesites.org/
- **Integrated Infrastructure Planning (IIP)** is a planning approach that builds on smart growth principles to pursue infrastructure investments that meet the needs of a growing population while minimizing potential impacts of climate (Eastern Research Group, 2011). Seattle is taking this approach with their Sustainable Infrastructure Initiative. Financial support of multiple infrastructure needs is advocated for projects that afford environmental and community benefits. The segregation of the departmental planning processes, was noted as presenting a difficulty for benchmarking current states, and measuring nonmonetary benefits.
- **Integrated Urban Water Management (IUWM)** is designed to help communities plan for sustainable water infrastructure through the use of decentralized solutions such as rainwater tanks and local wastewater recycling (Burn, Maheeplala, and Sharma, 2012; van Leeuwen et al, 2012). This approach may be particularly effective for sprawling areas where centralized water management systems are stretched to the point of inefficiency.
- **SmartCode** is a transect-based tool supported by the Center for Applied Transect Studies (CATS). The tool is an open code template designed for flexibility to create zoning codes or ordinances to meet local conditions. Conversely the tool enables developers to explore potential designs by removing many of the very detailed restrictions, such as setback requirements, used in conventional zoning. SmartCode tool is available free to communities online: **http://www.transect.org/codes.html**
- **A model to support land use decision making by determining the best use of non-urbanized areas** has been developed in Italy (La Greca et al, 2011). It classifies land

based on the degree of evapotranspiration and fragmentation. While lands that are highest in evapotranspiration and lowest in fragmentation are deemed most appropriate for conservation, lands with evapotranspiration levels at the middle are suggested for agricultural use. Those with the least fragmentation for larger commercial applications, those most fragmented or smaller Community Supported Agriculture farms or community gardens. The rubric may be particularly useful for communities without established parameters and with land use plans that don't yet differentiate between types of open space and agricultural uses.

- **OpenTERRAworks (OTW)** is an open access 2D/3D landscape design tool being developed by the EPA Sustainable and Healthy Communities Research Program and partners. The OTW supports comparative baseline and futures scenario modeling. Users can visually display changes to land, soil, and hydrography, including cut and fill operations, ditches, and bridges for simultaneous comparison with alternative scenarios. Originally designed to facilitate planning for coal mining at the surface, the tool has broad application to many land use modifications, such as for airport or golf course sitings. While OTW can help modelers develop inputs for use at multiple scales. After testing and quality assurance are completed, the tool will be openly available to the public.
- **The Housing + Transportation Affordability Index,** supported by the Center for Neighborhood Technology (CNT), enables users to calculate affordability of metropolitan areas nationwide for combined costs of real estate and transportation The index illustrates that the inclusion of transportation costs improves central locations based on affordable.
- **A methodology to disseminate and incorporate biodiversity and conservation data into local smart growth plans** has been developed by researchers at The Arizona Game and Fish Department and Arizona State University. The method allows planners to rapidly incorporate data into GIS models to prioritize potential areas for development to minimize land use impact on biodiversity (Underwood et al, 2011).

Tools to evaluate impacts and tradeoffs:

- **LUAIRTOX air toxics model** assists land use planners by estimating toxic air emissions given the industrial and commercially zoned land area, without the need to detail specific facilities. It is an interactive spreadsheet model that applies a published methodology to data from the California Air Toxics Inventory to generate aggregate emission factors for industrially and commercially zoned districts. It is designed to be a long-range planning tool to assess the community health risk implications of alternative land use scenarios at a regional scale (Willis and Keller, 2007). The model enables distinctions between carcinogenic and non-carcinogenic emissions to generate a spatially specific hazard index rating. The tool can help planners predict the general pattern of risk from industrial emissions. http://www2.bren.ucsb.edu/~mwillis/LUAIRTOX.htm

- **Eco-Flow software package.** This software facilitates analysis by-product synergy (BPS) networks to find optimal by-product flows within a defined area. A case study in Kansas City showed that industries working together could save up to $15 million annually through coordinated actions (Cimren, Fiksel, Posner, & Sikdar, 2011).
- **Industrial Ecosystem Toolkit.** This tool quantifies the impact of collaborative industrial networks designed to "reduce costs, employ assets more efficiently, increase revenue, reduce risks, and conserve natural resources (Joseph Fiksel, Bakshi, & Ieee, 2010)."
- **A conservation priority ranking** has been developed using the software Zonation that balances the tradeoffs between carbon storage, biodiversity conservation, agricultural value, and urban development potential (Moilanen et al, 2011). Though the ranking was developed for the British context, the methodology could be applied globally.
- **Cellular automata based GIS modeling** can be used to illustrate dynamic, geographically specific iterative processes which allows modeling of more complex processes than mathematical equations alone. This method has been applied to uses such as urban spatial growth, forest fire spread, and land suitability analysis for irrigated agriculture (Yu, Chen, and Wu, 2009).
- **InVEST software tool** has been used to help communities navigate ecosystem service tradeoffs such as between agricultural productivity and water quality or between financial return and carbon storage. A case study in Hawaii helped Kamehameha Schools allocate their land in the best way to prioritize the ecosystem services most important to the community including food security, climate change mitigation, and diverse rural economic opportunities (Goldstein et al, 2012).
- **Envision Integrated Modeling Platform** is a GIS-based framework to create alternative future scenario applications. The tool consists of a dynamic spatial engine and an open extensible architecture that allows any number of process models, evaluative models, visualizers, and analysis modules. Together, the framework allows simulation of land use change and documentation of resulting effects on indices of ecosystem, social, and economic services. http://envision.bioe.orst.edu/
- **i-Tree Hydro** allows the user to compare the effects of three scenarios-- pre developed, developed and green infrastructure -- on a variety of outcomes including surface runoff, infiltration, and pollutants. Through the online user interface, access to data inputs will be facilitated. http://www.itreetools.org/hydro/. Two other approaches exist to estimate the amenity value of street trees, CAVAT and Helliwell, both of which may be useful to communities with limited data collection capacity (Sarajevs, 2011).
- **Coastal Adaptation to Sea Level Rise Tool (COAST).** "The Coastal Adaptation to Sea Level Rise Tool" (COAST) makes it possible to assesses costs and benefits of

adaptations to sea level rise scenarios by incorporating a variety of existing tools and datasets into a comprehensive GIS-based picture of potential economic damage. The tool utilizes local LIDAR data and tax assessments, and property values to predict flood damage. Data output to Google Earth is enabled to visualize visualizes dollar amounts for individual land parcels. This local, visual approach is highly engaging for citizens. http://www.ebmtools.org/coastal-adaptation-sea-level-rise-tool-coast.html

Tools for collaborative planning:

- **Healthy Development Measurement Tool (HDMT)** was developed by the San Francisco Department of Public Health to make HIA more user-friendly (Dannenberg et al, 2011). The Sustainable Communities Index is a system of indicators to help communities develop ”livable, equitable and prosperous cities.” This site provides the methods and data sources required for collecting indicators for a particular city or region and resources for applying these metrics to planning, policy making and civic engagement. The tool provides a menu of more than 125 indicators, a checklist of development targets, and a selection of strategies to meet those targets. Finally evidence for the listed actions and impacts are provided. (Corburn, 2009, p200). HDMT is now used in several cities across the country and has been adapted for use in rural settings as well. An interactive web version of the tool is available online http://www.sustainablecommunitiesindex.org/
- **Frameworks to achieve sustainable agriculture** are being developed by researchers from England and Germany. The approach uses a systematic inventory to identify pertinent issues and possible solutions to agricultural practices in transparent way where the normative assumptions being made are clear, as opposed to many scenario modeling efforts (Walter and Stutzel, 2009). This method is intended to achieve greater stakeholder buy-in.

Informational resources

- **Growing Smart legislative guidebook** provides model statutes for planning and the management of change is a continuously updated electronic book freely available online. It details tools for state and local governments to help combat urban sprawl, protect farmland, provide affordable housing, and encourage redevelopment. The guidebook explains the process of planning statute reforms and provides detailed model statutes for use as a resource for practicing planners and local governments. http://www.planning.org/growingsmart/guidebook/
- **NARC Roadmap to Green Infrastructure** is a tool to assist local governments, regional councils and their communities, to better understand how each federal agency defines, implements and funds green infrastructure.
- **Visualizing Density** is an online photo essay put together by the Lincoln Institute of Land Policy to visualize density measurements and the way design affects the perception of density.

- **Sustainable Design and Green Building Toolkit for Local Governments** is a guide developed by the EPA in conjunction with participants of a workshop on overcoming barriers to green permitting. It provides a checklist to evaluate existing codes and ordinances consistent with sustainable best practices (US Environmental Protection Agency, 2010). http://www.epa.gov/region4/recycle/green-building-toolkit.pdf
- **Healthy Community Planning Toolbox,** developed by the Tacoma-Pierce County Health Department, provides worksheets and resources to help integrate health into planning documents in a way that fits a specific community context. http://www.tpchd.org/environment/planning-healthy-communities/healthy-community-planning-toolbox/
- **Sustainability Best Practices Framework** is a report published by the Institute for Local Government: it highlights specific community policies that support energy efficiency, clean water, green building, waste reduction, climate mitigation, efficient transportation, sustainable land use, and more. http://www.ca-ilg.org/sites/main/files/sustainability_best_practices_framework_7.0_version_june_2013_final_0.pdf
- **Safe Routes to Schools** is a national campaign of regional programs to promote walking and biking to school. Public safety, planning offices, schools, and parents are targeted to create safe streets and safe protocols for active travel to school. http://www.saferoutesinfo.org/
- **Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments.** This report outlines a process to identify local climate change risks, as well as to gather support, to implement a climate mitigation and adaptation plan: http://www.icleiusa.org/action-center/planning/adaptation-guidebook

Planning Philosophies and Organizations

- **Smart Growth** is a philosophy of urban planning and transportation designed to combat sprawl by concentrating growth in compact, walkable urban centers. Smart Growth advocates compact, transit-oriented land use that is walkable, bicycle friendly and designed for safe, ready access to neighborhood schools. The concepts of mixed-use development, and brownfield redevelopment with a range of housing choices are fundamental concepts for Smart Growth. These actions support preservation of open spaces and parkland, reduce the need for impervious surfaces, and the protection of critical habitat and water quality. It emphasizes infill and other strategies to limit green field development. The Smart Growth Network (www.smartgrowth.org) is composed of the EPA and more than 40 nonprofit and government organizations in support of ten smart growth principles.
- **New Urbanism** is a movement with many of the same tenants as smart growth that emphasizes architecture and place making to a greater degree. The group's charter advocates the following principles: "neighborhoods should be diverse in use and population; communities should be designed for the pedestrian and transit as well

as the car; cities and towns should be shaped by physically defined and universally accessible public spaces and community institutions; urban places should be framed by architecture and landscape design that celebrate local history, climate, ecology, and building practice." The Congress for the New Urbanism (www.cnu.org) has partnered with the US Department of Housing and Urban Development, the US Environmental Protection Agency, the Federal Highway Administration, and the US Green Building Council, among others to accomplish a variety of projects.

- **Lifelong Communities** (also called "aging in place). This approach emphasizes community interventions which support safe, comfortable and independent living regardless of age, income, or ability level. Their principles include improving accessibility through transit, walkability, and compact design, improving services at the neighborhood scale, increasing the variety of housing types and housing affordability, and more. The goal is to foster communities where individuals can live throughout the major transitions in their lives, as a student, young adult, parent, retiree, and elder
- **Placemaking** is a philosophy that emphasizes the important role of public spaces and walkable uses in creating vital communities that people find attractive and welcoming. By highlighting unique community assets, advocates intend to create spaces that support social capital and local prosperity. The movement critiques the standardized form of typical suburban developments for creating spaces devoid of character. The Project for Public Spaces (http://www.pps.org/) has developed a guide to creating great federal public spaces for the US Department of Housing and Urban Development (http://www.pps.org/projects/propertymanagersguide/).
- **Just sustainability** is parallel concept to environmental justice that emphasizes intergenerational equity. Both share an affirmation of the potential for environmental and land use decisions to disproportionately affect the poor and minorities. Agyeman (2013) has described that "a truly just sustainable society is one where wider questions of social needs, and welfare, and economic opportunity

Appendix C *ORD Tasks Listed in This Document*

ID#	TASK	TASK LEAD
	SHC	
1.1.1.2	DASEES	Brian Dyson NRMRL/LRPCD
1.1.1.3	Perspective Analysis and systems framing	Marilynn Tenbrink, NHEERL/AED
1.2.1.3	Suite of SHC tools that allow full value accounting	Allen Brookes NHEERL/WED
1.2.2.1	Inventory of Sustainability Indicators	Tarsha Eason NRMRL/STD
1.2.3	Creation of Foundational data necessary for calculation of metrics for EnviroAtlas	Anne Neal NERL/ESD
2.1.1.1	Classification: defining and classifying ecosystem services to link with human well-being and to avoid double counting	Dixon Landers NHEERL/WED
2.1.2.1	Ecosystem Goods and Services Production Function Library	Randall Bruins NERL/EERD
2.1.2.4	Uncertainty, scalability, and transferability of ecosystem goods and services	Theodore Dewitt NHEERL/WED
2.1.4.1	Tampa Bay Ecosystem Services Demonstration Pilot	Marc Russell NHEERL/GED
2.1.4.3	Wetlands-Understanding the provisions of ecosystem services provided by wetlands and their use in sustainable land and water	Timothy Canfield NRMRL/GWERD
2.1.4.4	Human Communities benefit from Great Lake coastal ecosystems	David Bolgrien NHEERL/MED
2.2.1.1.	Public Health conditions: Data Integration to improve Community Health Assessments	Timothy Wade NHEERL/EPHD
2.2.1.5	Development and application of community-based decision support tools	Valerie Zartarian-Morrison NERL/HEASD
2.2.1.6	Lessons learned, best practices and stakeholder feedback from community and tribal participative case studies	Florence Fulk NERL/EERD
2.2.3.5	Apply integrated transdisciplinary and community-based participatory approaches to conduct cumulative community assessments	Timothy Barzyk NERL/HEASD
3.1.2.1	Innovative approaches to support the measurement and assessment of vapor intrusion into Homes/Buildings from contaminated site	Brian Schumacher NERL/ESD
3.1.4.5	Research supporting L.U.S.T. Sites	James Weaver NRMRL/GWERD
3.1.5.1	Subsurface contaminant remediation	Richard Wilkin NRMRL/GWERD
3.3.1.2	Informing sustainable nitrogen decisions using an ecosystem services framework	Jana Compton NHEERL/WED
3.4.1.1	Sustainability Indicators for the ROE	Patricia Murphy NCEA/IO
3.4.1.2	Annual update of ROE data sets	Patricia Murphy NCEA/IO
	ACE	
137	Integrated climate and land use tools data sets for impacts, vulnerability and adaptation assessments	Britta Bierwagen NCEA/IO

155	Linkage with Global climate models: Downscaling techniques	Tanya Otte NERL/AMAD
	SSWR	
4.1.A.1	Mitigation through multi-scale implementation of green infrastructure in communities	William Shuster NRMRL/STD
4.2.A.	Place based and experimental monitoring of green and grey infrastructure, best management practices (BMP), and BMP treatment trains	Michelle Simon NRMRL/WSWRD
7.1A	Highly Targeted Programmatic Support	

Appendix D *WORKS CITED*

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Appendix E *JOURNALS CITED*

Appendix F *RESOURCES CONSULTED*