GREEN STORMWATER INFRASTRUCTURE & HUMAN HEALTH BENEFITS

LITERATURE REVIEW FOR RESEARCH PLANNING

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1. PURPOSE

The primary purpose of this report is to provide the knowledge base for potential research on a co-design for co-benefits approach to green stormwater infrastructure. It provides an overview of existing research on nature experiences and human health in urban settings. The materials provided here represents a subset of literally thousands of science articles that have been published in recent decades. The research literature spans disciplines of public health, epidemiology, urban planning, various social sciences, landscape architecture and economics.

A secondary purpose is to begin an exploratory process to develop research design(s) that can be used to investigate specific health responses associated with green infrastructure installations in the metro Seattle and King County region. This process would involve discussions about research outcomes that are particularly relevant, or of higher priority, to Seattle area communities, and available resources (fiscal and technical).

The organization of this report is:

- Section 2 – **Introduction and Background** – overview of green infrastructure co-design for co-benefit opportunities.
- Section 3 – **Process** – sourcing and synthesis of research findings about nearby nature and health outcomes.
- Section 4 – **Benefits Framework** – description of the general themes of evidence from research literature.
- Section 5 – **Potential Metrics** – overview of social science and epidemiological research approaches to assess GSI design for human health.
- Section 6 – **Nature & Health References** - table of research citations, organized by the benefits framework, serving as a resource for future research constructs and methods.

2. INTRODUCTION & BACKGROUND

More than 80 percent of the Washington State population lives in urbanized areas, and the state's urban counties are some of the fastest growing in the nation. The combination of increased population and growth management policies (that urge urban densification) place ever-greater pressures on existing urban green spaces. In many communities land may not be available for additional parks; in other places land may be available, but there may not be the fiscal resources needed to create and manage new green spaces.

Research confirms that having even the smallest bits of nature near the everyday places of city life provide surprising levels of social, psychological, and health benefits. All urban systems—housing, energy, zoning, transportation— are designed for safety and efficiency; a comprehensively planned systems parks, landscapes, and open spaces is also needed to assure positive quality of life for city residents.

Another urban dynamic is the rapid evolution of green infrastructure. Generally, green infrastructure is the conservation and creation of natural systems that are integrated with built systems to sustain ecological balance in urban landscapes. In many urban communities, green infrastructure is being used to augment the performance of traditional "gray" infrastructure. Within this broader concept is green stormwater infrastructure (GSI), which refers specifically to water management, especially runoff.

If green infrastructure is designed to include compelling natural spaces, nature and people both benefit. Decades of research from the social sciences, public health, and design professions indicate that even small outdoor spaces can serve to reduce particular health risks (e.g. skin cancer, obesity, asthma),

encourage general wellness (e.g. reduced blood pressure, heart disease, and stress), and accomplish specific social or psychological benefits (improved cognition, mindfulness, and social cohesion).

Green infrastructure is an emerging and important strategy for supporting healthy urban ecosystems. GSI is used to place small to large ecology-based water management features in both private and public spaces within communities. With a little extra attention to design, GSI can also be used to promote healthier human communities.[1]

The technology of GSI design and construction is evolving rapidly. GSI offers a variety of opportunities to bring more health-oriented greening into the everyday places where people live, work, learn and play. It can even be envisioned as a system of connected micro-parks that offer close-at-hand contact with nature. Providing nature experiences across a comprehensive, connected system can generate a wider spectrum of benefit than site-by-site installations.[2]

A co-design for co-benefits commitment is timely and highly feasible. As these functional landscapes are created there are opportunities to evaluate human response, as installations are potential settings for 'natural experiments' for both engineering and public health outcomes.

This informal literature review highlights general themes of human health and wellness that are derived from nature experiences. It contains a summary framework of research highlights, and a general overview of the research methods used to build the evidence base. The next activity following this report will be to discuss, with key partners:

- research design options, including
- health benefits priorities,
- potential beneficiaries, including environmental equity goals
- measurement feasibility, and
- study site opportunities.

3. PROCESS

The research literature listed later in this report was derived from another project at the University of Washington. The Green Cities: Good Health web site is an informal review of the nature and health research literature. Its creation was supported by the USDA Forest Service. It is intended to be an informational resource for policy makers, professionals and urban resources managers. Publications representing nearly 40 years of science across numerous disciplines has been collected and sorted into about a dozen benefit themes. The publication database that supports this project now numbers at approximately 5,000 publications, with more than 4,000 being peer-reviewed journal articles. Using

[1] Wolf, K. L., 7 The Nature Conservancy. 2018. Cascading Benefits: Designing Green Stormwater Infrastructure for Human Wellness. The Nature Conservancy: Seattle, WA, 24 pp.

[2] Ekkel, E.D., & de Vries, S. 2017. Nearby green space and human health: Evaluating accessibility metrics. *Landscape and Urban Planning* 157, 214-220.

document management software, the publications collection was screened to extract and summarize the benefits evidence that is most relevant to GSI installations.

4. BENEFITS FRAMEWORK

The article screening resulted in a framework of health benefits that could be achieved with GSI co-design for co-benefits. More detailed information and specific citations are provided in Section 6. Here you will find a narrative overview of the benefits framework.

There are several social dynamics imbedded within the research. The first is the specification of beneficiary population. Early in the history of the health research, studies tested university students or adults and generalized to all people. More recent studies are more differentiated, addressing the specific needs and responses of:

- people of different ages, from infants to elders,
- people of differing cultural backgrounds,
- people of varied socio-economic resources, with particular attention to underserved individuals or communities,
- people with a healthy baseline, versus those with clinical diagnoses of disease or disorders.

The second general dynamic across the studies is human scale, with studies ranging in focus from:

- individuals – for instance, a worker walking during a lunch break, or a person with depression doing a forest walk,
- families - parents taking their child on routine walks for reduced ADHD symptoms, or nature buffers reducing extreme noise for a household,
- small social groups – neighbors increasing social cohesion due to routine walks in a nearby park, or benefits from participation in neighborhood street tree care, and
- neighborhoods and communities - reduced crime due to visitors providing ‘eyes on the street’ informal policing, or roadside vegetation encouraging traffic calming making safer settings for pedestrians and cyclists.

PHYSICAL HEALTH & WELLNESS

Many studies have explored and confirmed that physical activity is a behavioral pathway that helps people manage their weight, reduce cardiovascular and respiratory disease, and reduce diabetes symptoms. In addition, routine physical activity in nearby nature can help reduce stress, improve immune function, and even extend the life of older adults. The levels of routine moderate physical activity that are recommended by health officials can be achieved by recreational walking or running, active transit, and cycling – all are activities that will be supported by GSI installation in parks, streetscapes, and civic spaces.

MENTAL HEALTH & FUNCTION

Mental health is a health concern gaining greater attention across our region and nation. One in five adults in the U.S. have a mental health condition, and depression is increasing dramatically in young people.[3] Expensive medications and treatments often follow diagnosis of mental disorders. Experiences of nature are linked to preventive approaches, as well as situations that reduce disease symptoms for people with a clinical diagnosis. Examples of the latter include adult depression and ADHD in children. In addition, contact with nature is proven to improve cognitive function. Desk workers and students show increased performance, less mental stress, and improved task focus if they have access to nature. Creative workers find that nature experiences nudge the ideation process. People recovering from life-changing medical treatments (such as cancer) have found that frequent nature experiences help them to return to a normal lifestyle.

SOCIAL DYNAMICS/COHESION

Public health and medical strategies once focused on the individual person and their behaviors, but it has become obvious that the character of a community and one's social connections also have important implications for health. People who are socially isolated or lonely are more prone to illness, take longer to recover from disease or surgeries, and have poorer general health. This is particularly true for elderly people, often more prone to being removed from social interaction. Parks and outdoor spaces are where informal contacts occur, providing opportunities to build relationships within a community. Having quality green space in a community also plays a role in reduced aggression and lower rates of personal and property crime. Finally, people who participate in learning about nature, and are involved in stewardship programs display health benefits that continue beyond events or projects.

REDUCED RISK

People who live in cities encounter a variety of risks and challenges in everyday life. People living in underserved communities, including some of the neighborhoods in the more southern and northern areas of Seattle, may have greater exposure to such risks. Urban planners and officials work to improve urban human habitat, and nearby nature can mitigate some negative conditions. For instance, tree canopy and shade can reduce the effects of sun exposure and high heat episodes in the summer, and the cooling effects of green spaces extend into adjacent areas beyond a vegetation patch. Tree canopy also captures fine particles in the air, known to cause respiratory discomfort, and often found at higher densities near busy streets. Excessive noise, such as from high volume traffic ways, can cause health issues such as stress and chronic headaches, and vegetation buffers reduce decibel levels.

ECONOMIC VALUE

Some of the most recent research in the nature and health field is revealing substantial economic cost recovery. Nature experiences are both a preventative health strategy and can provide a marginal level of

[3] Nguyen, T., & Davis, K. 2016. *The State of Mental Health in America 2017.* Mental Health America: Alexandria, VA.

healing or therapy for people with clinical illness. The national health care services bill in the U.S. is now more than $3 trillion per year, nearly 18% of the national G.D.P. Nature benefits evidence implies potential costs savings of reduced medications, hospitalizations, therapy, and need for extended care. While very preliminary, the calculations of savings, if communities were to have high quality nature available to all residents, would be in the billions of dollars per year.[4]

5. POTENTIAL METRICS

The pace of research publication about nature and human health response has accelerated dramatically in the past decade. More research funding is available for studies, and the next generation of scientists are devising more diverse and clever measurement approaches. Converting this report to study development will include discussions of methods that will both evaluate a health outcome of interest, and be feasible for a community-based research situation. The range of measures include:

- self-report – often administered as surveys or phone interviews using validated verbal prompts, with measures taken once or multiple times, and the respondent is asked about current and/or historic conditions,
- archived data – data available from city, county, national, U.S. census, or standardized health surveys that is accessed from a public source and compared to a landscape or green space condition,
- objective or observational measures – respondents are tested with devices or instruments to determine physiological responses such as cortisol levels, heart rate, blood pressure, EEG brain readings; used more often in controlled field or laboratory settings, though portable devices are becoming more common, and
- personal technology monitoring – smart device applications can be used to record location and activity levels (e.g. accelerometers) and link the data to periodic mood, weight, or other physical measures that are self-report and can be prompted by texts or phone calls.

[4] Wolf, K. L., Measells, M. K., Grado, S. C., & Robbins, A. S. 2015. Economic values of metro nature health benefits: A life course approach. *Urban Forestry & Urban Greening* 14, 694-701.

6. NATURE AND HEALTH REFERENCES

Listing of research about human health and wellness benefits associated urban nature experiences relevant to GSI facilities, organized by benefits framework of:

- Physical Health & Wellness
- Mental Health & Function
- Social Dynamics/Cohesion
- Reduced Risk

Experience, Behavior or Pathway	nature experience	beneficiary population	adjacency	outcome detail	literature support	monetization strategy
Physical Health & Wellness						
routine moderate physical activity	green settings associated with more consistent activity	children, adults, older adults	residential and nearby businesses	weight management, reduced CV and respiratory disease, reduced physiological stress, reduced diabetes, reduced depression	Active Living Research program[1]	partial reduced/deferred treatments & medications
active transit/commuting	mobility choices that include nature, Green Street strategies	employees, students	nearby businesses and schools	weight management, reduced CV and respiratory disease, reduced physiological stress, better work/student performance and success	Flint & Cummins[2]	partial reduced/deferred treatments & medications, reduced transportation costs
elder longevity	nearby neighborhood greening	elders	residential	ambient green associated with reduced mortality, active & passive nature experiences reducing chronic disease, maintain social cohesion	Takano et al.[3], Kweon et al.[4]	partial reduced/deferred treatments & medications plus reduction in long term care costs (longer but healthier), less costs due to loss of mobility, better health of associated care givers
physiological stress reduction	distributed eye-level nature & nature sounds	adults	episodic visitors, residential, businesses	reduced blood pressure, reduced cortisol, improved immune function	Ulrich et al.[5], forest bathing[6]	partial reduced/deferred treatments & medications

Experience, Behavior or Pathway	nature experience	beneficiary population	adjacency	outcome detail	literature support	monetization strategy
biophilic response (mental & physical) in built environments	distributed eye-level nature, nature sounds, bioregional/native species	all	all	sweeps in most physical and mental health outcomes, familiarity and appeal, leading to increased encounters	Terrapin Bright Green[7], Kellert et al.[8]	partial reduced/deferred treatments & medications, attraction to place, thus more spending over repeat visits
population level health improvements	living within a district or neighborhood having well managed metro nature (trees, parks, gardens, green space)	children, adults, adolescents, older adults	residential	broad measures, such as hospital visits, work/school absenteeism, county health records, formal and informal surveys of self-reported health	Groenewegen et al.[9], Maas et al.[10], Donovan et al.[11]	reduced care and treatment costs by health care clinics, hospitals, and medical professionals; city and/or county health program savings
Mental Health & Function						
worker walks and runs	surrounding gardens and trees, activity facilities, activity programs	employees	nearby businesses and firms	contact with nature associated with mental restoration and improved cognitive function, reduced absenteeism/presenteeism, higher job satisfaction, greater creativity	Kaplan[12], Korpela et al.[13], Plambech et. al.[14], Marselle et al.[15]	productivity quotient of cumulative employee outputs within and across firms
routine walks for ADHD	outdoor play environments, compatible walking facilities	diagnosed children	residential	reduced ADHD symptoms for children active outdoors, more than indoor activity	Faber Taylor et al.[16], Kuo et al.[17]	partial reduced/deferred treatments & medications
children at play, cognitive & physical development	structured and unstructured play	resident children	residential	development of creativity, social intelligence, fine & gross motor skills	Louv[18]	social and physical developmental benefits that precede adult capacities
routine walks for depression	outdoor environments, compatible walking facilities (streets or parks)	diagnosed adults	residential	reduced symptoms, improved mood, reduced rumination	Berman et al.[19], Bratman et al.[20]	partial reduced/deferred treatments & medications
reduced mental stress/restorative experiences	nearby greenspace, favorite places, 'soft fascination' nature	adults, youth	residential	reduced stress and associated psych disorders, improved crisis recovery	Bratman et al.[21], Korpela et al.[22], Ottosson & Grahn[23],	partial reduced/deferred treatments & medications, greater productivity

Experience, Behavior or Pathway	nature experience	beneficiary population	adjacency	outcome detail	literature support	monetization strategy
					Grahn & Stigsdotter[24]	
increased happiness & life satisfaction	presence of nature, everyday exposure (passive & active)	adults	residential	general reports of increased life satisfaction & general well-being	Ambrey[25], Larson et al.[26], MacKerron & Mourato[27]	civic assets substitute for private/household costs (e.g. larger home/yards)
students near and in green learning environments	window views, outdoor activity, environmental learning	students to young adult	campuses	better school performance, graduation rates	Matsuoka[28], Li & Sullivan et al.[29], Kweon et al.[30]	costs to school district or remedial classes, student tutoring costs, income loss from not graduating
adolescents and young adults and 'good choices'	nearby greenspace, favorite places, 'soft fascination' nature	students to young adult (particularly girls)	residential	nature association with cognitive capacity to focus, fend off mental distraction, Attention Restoration Theory	Kuo[31], Taylor et al.[32], Kaplan & Berman[33]	life and career consequences, reduced costs of 'bad choices' (such as court costs or counseling)
better cognitive recovery following medical treatment	walking within/views of nature	people in recovery after high impact treatment, e.g. cancer patients	residential	better life management and restoration of lifestyle, reduced stress for households and loved ones	Ray & Jakubec[34], Cimprich[35]	partial reduced/deferred treatments & medications plus faster return to work & life duties, reducing substitution costs
Social Dynamics/ Cohesion						
increased positive engagement with household, family, friends	favorable landscape spaces, supportive facilities	episodic & long term visitors	nearby residential	improved general health, illness & treatment recovery, family cohesion, social capital	Kuo 2003[36], Tercan[37]	reduced self-destructive behaviors (e.g. substance abuse), reduced family counseling
talent recruitment & retention	accessible nature amenities	workers	nearby businesses	quality of workplace attraction (with market +?)	oft claimed but did not find study	reduced costs for recruiting new employees and start up training of individuals (up to a year)

Experience, Behavior or Pathway	nature experience	beneficiary population	adjacency	outcome detail	literature support	monetization strategy
restoration volunteerism	sustained, direct site/vegetation work	residents/ workers, youth	nearby residential/ businesses	social cohesion, social capital, more positive emotions, self-enhancement	Asah et al. 2014[38], Lu & Schuett 2014[39], Anderson et al.[40], Ryan 2015[41]	associated physical and mental health benefits, deferred personal education costs, improved mental and physical capacity for elders, reduced landscape management costs
crime reduction	amenities encourage frequent user presence resulting in social policing, CPTED	episodic & long term visitors	residential	reduced reported personal & property crime	Sullivan et al. 2004[42], Bellair 1997[43]	reduced costs of area monitoring and surveillance, such as police staffing or CC camera systems
reduced household aggression	surrounding greenspace	adults, adolescents	residential	mitigating mental fatigue reduces interpersonal aggression	Kuo & Sullivan 2001[44], Younan 2016[45]	reduced mental duress costs, perhaps negative coping strategies (e.g. alcohol), deferred professional services
nature learning, displays & institutions	interpretation of green infrastructure, Puget Sound (e.g. Aquarium), urban forestry	children, adults	site visitors, residential, workers	environmental values, place-based learning, heightened altruistic attitudes	Chawla 2007´[46], Korpela et al. 2008[47], Guéguen and Stefan, 2017[48]	relationships to mental and physical health benefits plus greater support for public investment in natural resources
unique city & neighborhood civic amenities	nature amenities as primary experience of place	residents, workers, visitors	residential, private sector management	place attachment, place identity, favorite place response including caring/ belonging/ happiness, restorative environments	Manzo 2016[49], Zelenski and Nisbet 2014[50], Korpela et al. 2010[51], Korpela and Hartig 1996[52]	reduced household costs for staycations vs getting away, charity giving for local change
cultural & arts events support (attitude & fiscal)	nature based settings & programming	episodic & visitors, civic organizations	site visitors, residential, workers	place attachment development, place-based learning and development, diversity and equity appreciation, integrated community, social capital	Putland 2008[53], Newman et al. 2003[54]	greater support for public investment in arts and cultural resources, tourism recruitment
Reduced Risk						

Experience, Behavior or Pathway	nature experience	beneficiary population	adjacency	outcome detail	literature support	monetization strategy
variable higher positive impact for lower socioeconomic communities	general green character	less affluent vs more households & neighborhoods	nearby residential	associated with community-based health disparities, underserved communities typically respond more positively to nature introductions	Maas et al. 2009[55], Abelt & McLafferty 2017[56], Jennings et al. 2017[57]	partial reduced/deferred treatments & medications, though concerns about dislocation/gentrification
reduce heat episode impacts	having distributed vegetation, canopy shade	all	site visitors, nearby residential, more vulnerable populations (children & elderly)	reduced dehydration/heat stroke/exhaustion, improved thermal comfort, reduced propensity to respiratory & cardiovascular (CV) issues	Du et al. 2017[58], Howe et al. 2017[59], Sugawara et al. 2016[60], Snir et al. 2016[61], Morakinyo et al. 2017[62]	partial reduced/deferred treatments & medications, reduced mortality
buffer traffic & other high level noise	street level vegetation & gardens	all	site visitors, nearby residential	reduced stress response & CV response, improved sleep, improved diabetes symptoms?, improved work/school performance	Casey et al. 2017[63], Van Renterghem & Botteldooren 2016[64], Dzhambov & Dimitrova 2014[65]	partial reduced/deferred treatments & medications, productivity gains
reduced fine particulates in air	particulate adherence in trees, and multi-layer vegetation structure	all	site visitors, residential	reduced respiratory irritation, perhaps less asthma, more outdoor activity	Abhijith et al.[66], Yli-Pelkonen[67], Jeanjean et al. 2017[68], Morakinyo and Lam 2016[69], Escobado & Nowak 2009[70]	partial reduced/deferred treatments & medications
reduced solar & UV exposure	thin but uniformly distributed shade	all, children	repeat and episodic visitors, nearby residential, business	research results mixed so careful tree placement needed, reduced skin exposure and burns, most important for children, particularly important frequent users or extended events visitors (such as a mid-day concert)	Diffey 2002[71], Grant et al. 2002[72]	reduced discomfort so more time spent in leisure & recreation

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