Green Infrastructure in Urban Centres: Policy, Design and Practice

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Contents

WELCOME

This online course is for policy makers and professionals seeking to understand green infrastructure (GI) and its potential for managing the impacts of water in urban settings. Participants in this course will join the network of professionals engaged with the challenges and opportunities of blending nature and infrastructure.

Green infrastructure and related nature-based solutions are gaining widespread support as effective components of healthy city building as well as as climate adaptation strategies. The course provides an overview of how GI systems work, the benefits they can provide, and how they can be employed effectively. The 12 modules of the course lay out a comprehensive overview of the current and growing green infrastructure theory, design, and practice and the associated challenges and opportunities.

- **Modules 1-3 The Grey to Green Transition** identifies the different types of GI, the reasons that motivate cities, suburbs, and towns to adopt and expand GI systems, and the multitude of benefits associated with them, and showcases successful employment of specific GI strategies.
- **Modules 4-6 Design and Implementation** discuss the principles and practices behind successful GI design and implementation, identifies design elements, targets and guidelines used to regulate GI implementation, and considers the data needed to inform GI design and implementation decisions, and potential sources for the relevant data.
- **Modules 7-9 Policy and Governance** focus on the policies, institutions, and systems that govern and drive green

infrastructure employment in cities around the world, highlights specific tools and regulations for GI, and compares and contrasts GI policies and governance.
- **Modules 10-12 Planning and Leadership for Green Cities** review recent advances and most innovative examples of GI design, policy, and practice. This section explores what GI may offer cities in the future and how these progressive visions might be realized.

Funding for this course is provided by Adaptation Learning Network, (Links to an external site.) an initiative supported through Natural Resources Canada BRACE (Links to an external site.) and the BC Ministry of Environment and Climate Change Strategy.

Course Material

This course consists of written material, readings, videos, and activities designed to enhance understanding of core concepts and evolving best practices of GI. The course draws on primary and secondary sources, practitioner knowledge and has been reviewed by leading experts in the field.

The course is primarily self-guided. Working through the module will take up to three hours to complete. Learning activities for each module are in the form of active group discussions, reflection pieces, quizzes and case study research. Additional resources are also included in each module should you wish to pursue further study beyond the scope of this program.

Core Documents

The following documents will be referenced throughout the course. And although you won't be expected to read all of them in one sitting, they are excellent resources to keep handy during the course and beyond.

- Integrating Grey and Green: Creating Next Generation Infrastructure (World Bank, 2018)
- Blue and Green Cities: The Role of Blue-Green Infrastructure in Managing Urban Water Resources (Brears, 2018) (Note: this book is coyprighted).
- Green Infrastructure Case Studies and Lessons Learned (USEPA)
- Urban Green Infrastructure Planning: A Guide for Practitioners
- Rain City Strategy – City of Vancouver

About Adaptation Learning Network

Welcome to the Adaptation Learning Network (ALN). This course is one of ten courses developed for working professionals. These courses are designed for people who are addressing climate adaptation risks and impacts in their communities and jobs.

WHY DOES THIS MATTER?

Climate change adaptation requires expertise from many perspectives. The ALN is committed to connecting people, professional interests, and regions to advance skills, knowledge and solutions.

JOIN THE NETWORK

To join the network, sign up for our monthly newsletter here, and follow us on social media (Twitter, LinkedIn) to get adaptation news and hear about our latest course offerings and events.

LEARN MORE

To learn more about the Adaptation Learning Network read this 5-minute introduction.

Learning Objectives

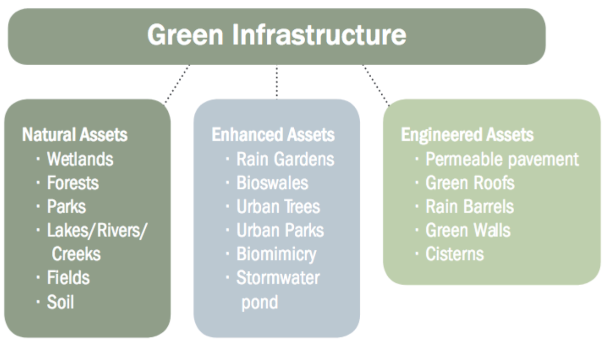
- Examine the terminology used to describe green infrastructure systems,
- Discuss what role green infrastructure has in addressing urban challenges.

Introduction

Welcome to the first module of the Green Infrastructure course. It makes sense to begin first by introducing yourself to other members of the class – as you will find this network of professionals to be a very rich resource for your continued learning journey.

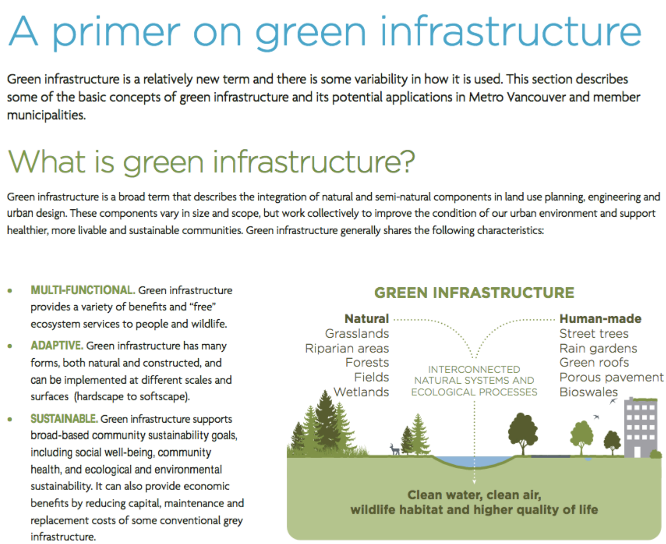
We are excited to begin this learning experience by clarifying some basic definitions for Green infrastructure (GI) and explore the fundamentals of GI. We begin with the assumption that urban centres face three main challenges with regard to water management: storm flooding, water pollution and water shortages. Urban areas around the world are working to reduce runoff and pollution, and also to restore downstream ecologies. This occurs when low impact development methods are integrated with grey infrastructures, large-scale flood control projects and ecological rehabilitation. There are some promising experiments taking place worldwide with Green Infrastructure systems to support these efforts.

Green infrastructure is a broad category that includes both natural ecosystems and engineered systems created to mimic the natural functions and services provided by healthy ecosystems to human communities. Green infrastructure is referred to using various terms including natural asset infrastructure, low-impact development, green rainwater infrastructure, blue-green infrastructure, etc. Each term has been developed to describe a system focused on distinct outcomes and often on a particular scale. When you read the article by Fletcher, it will give you a sense of how these terms are used and how they have evolved over time. For the purposes of this course, we will focus primarily on enhanced and engineered green assets, particularly as they relate to water.



Source: https://mnai.ca/media/2019/07/ SP_MNAI_Report-1-_June2019-2.pdf

GI is considered a strategy for mitigating the harmful impacts of urban stormwater runoff and has been implemented in cities around the world. Also referred to as Green Rainwater Infrastructure (GRI) or Low-Impact Development (LID), these systems have the capacity to capture, infiltrate, treat, and convey urban runoff safely into the natural environment to avoid pollution, flooding, and many other unintended consequences. GI systems have been found to eliminate over 90% of pollutants that were commonly found in roadway runoff by way of infiltrating runoff through soils and plant tissues. In addition to natural GI, enhanced and engineered GI systems – often in the form of green roofs, bioretention cells, and permeable pavements – are capable of retaining 50-70% of annual stormwater runoff when maintained properly. This graphic provides a big picture primer.


A primer on green infrastructure

Green infrastructure is a relatively new term and there is some variability in how it is used. This section describes some of the basic concepts of green infrastructure and its potential applications in Metro Vancouver and member municipalities.

What is green infrastructure?

Green infrastructure is a broad term that describes the integration of natural and semi-natural components in land use planning, engineering and urban design. These components vary in size and scope, but work collectively to improve the condition of our urban environment and support healthier, more livable and sustainable communities. Green infrastructure generally shares the following characteristics:

- MULTI-FUNCTIONAL. Green infrastructure provides a variety of benefits and "free" ecosystem services to people and wildlife.
- ADAPTIVE. Green infrastructure has many forms, both natural and constructed, and can be implemented at different scales and surfaces (hardscape to softscape).
- SUSTAINABLE. Green infrastructure supports broad-based community sustainability goals, including social well-being, community health, and ecological and environmental sustainability. It can also provide economic benefits by reducing capital, maintenance and replacement costs of some conventional grey infrastructure.

Source: Page 6 of http://www.metrovancouver.org/services/regional-planning/PlanningPublications/ConnectintheDots.pdf

Broadly speaking, green infrastructure (GI) encompasses any system that uses ecosystem functions to provide a service to human societies. GI systems vary significantly in their purpose, capacity, and complexity – however, all are assets that require ongoing strategic asset management. While green infrastructure is anything that uses biological systems and ecosystem functions to provide a service to humanity, effective green infrastructure does so without degrading those systems or functions. Here are some of the systems we will talk about in this course and what they are designed to do:

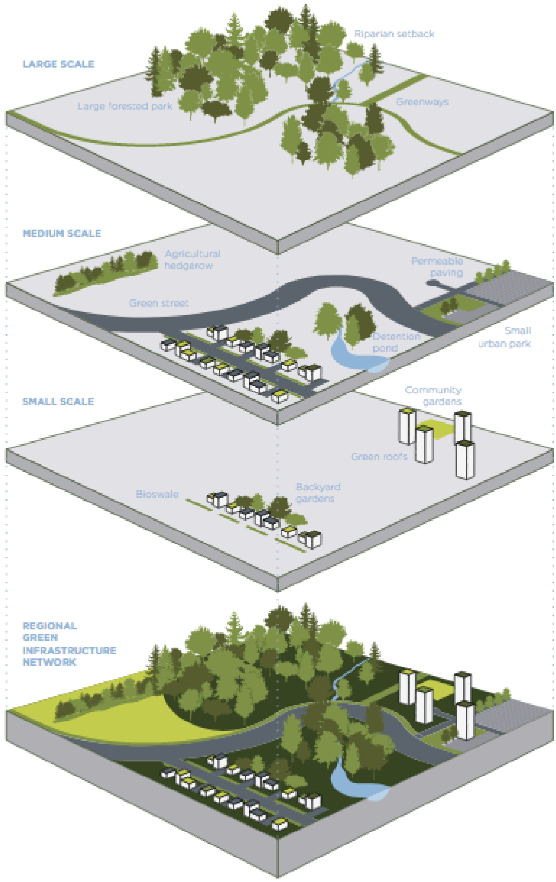
Green Infrastructure and Catchment Scale Effects

(a) Bioretention systems	Small depressional areas with soil filter media and native plants to promote soil infiltration and decrease rapid runoff
(b) Green roofs	Rooftops covered with lightweight growth media and vegetation that enable rainfall infiltration and recover evapotranspiration
(c) Rain gardens	Shallow and smaller vegetated areas, compared to bioretention systems, that use native soil to collect and infiltrate runoff
(d) Permeable pavements	Porous material that allows rainfall to gradually infiltrate into soils through open voids on the surface, with the potential to decrease rapid runoff
(e) Bioswales	Vegetated channels with engineered soils that infiltrate rainfall and runoff from upgradient impervious areas
(f) Rain barrels	Containers that collect and store rainfall that, if properly used, can slow and reduce runoff

Source: Table 1. Summary of Common Low-Impact Development (LID) Practices by Heather E. Golden and Nahal Hoghooghi is licensed under a CC BY NC license.

Conventional (or grey) infrastructure benefits from decades of precedent and well-established, straightforward design guidance to help engineers meet quantifiable outcomes: load-bearing capacity, sewer discharge rates, reservoir storage, etc. While assessing the performance of conventional infrastructure is an established practice, methods for assessing all of GI's benefits are only beginning to be understood, developed, and distributed. Measuring the performance of the GI is significantly more complex because it aspires to provide more for urban spaces than conventional grey infrastructure. Ecological and societal benefits are more difficult to quantify than the conveyance capacity of a pipe. The ecosystem services supported by GI operate on a variety of scales and can serve multiple functions: water quality improvements, enhanced water security, pollination, enhanced food security, health and wellness improvements, enhanced livability, and urban biodiversity. This diverse array of benefits provides GI with a compelling cost-benefit analysis.

Scales of GI



Components of green infastructure link together to form a functional network

Source: Page 8 of http://www.metrovancouver.org/services/regional-planning/PlanningPublications/ConnectintheDots.pdf

As you will explore in upcoming modules, urban drainage and the integration of grey with blue-green cities through the implementation of GI is not only providing co-benefits such as supporting the management of stormwater, reducing the heat island effect, improving water quality, enhancing water security, and providing benefits to health and wellness, it is also contributing to climate change resilience.

Learning Activities

- Read the four short articles and view the video for this module.

Discussion Question

- Introduce yourself and share your learning goals for the course.

Readings & Resources

Readings

- EPA Green Infrastructure Guide
- Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S.,

Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525–542. https://doi.org/10.1080/1573062x.2014.916314

- Blue and Green Cities: Blue-Green Infrastructure in Managing Urban Water Resources (pg. 43-57) (Note: this book is copyrighted).

Videos

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https://pressbooks.bccampus.ca/greeninfrastructure/?p=5

Additional Resources and Citations

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=5

- CVC LID Factsheets

- NACTO Green Infrastructure Guide

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=5

- Bartesaghi Koc, C., Osmond, P., & Peters, A. (2017). Towards a comprehensive green infrastructure typology: A systematic review of approaches, methods and typologies. *Urban Ecosystems*, *20*(1), 15–35. https://doi.org/10.1007/s11252-016-0578-5
- Young, R., Zanders, J., Lieberknecht, K., & Fassman-Beck, E. (2014). A comprehensive typology for mainstreaming urban green infrastructure. Journal of Hydrology, 519, 2571–2583. https://doi.org/10.1016/

j.jhydrol.2014.05.048

Module 2: Motivations for the Grey-to-Green Transition

Learning Objectives

- Examine the motivations behind green infrastructure systems and their potential for improving urban resilience to climate change and urban development.

Introduction

Don't it always seem to go
That you don't know what you've got
'Til it's gone
They paved paradise
Put up a parking lot

– Joni Mitchell

In 1970, Joni Mitchell's Big Yellow Taxi alluded to the truth that the essential services natural areas provide to human communities were only truly recognized in their absence. It took the absence of forests in upstream areas and the consequent flooding of city streets and properties for scientists and engineers to understand that forests absorb significant amounts of rainfall, slowing its progression towards rivers and stream and transforming intense rainfall events into steady stream flow instead of rushing, erosive torrents. It took the creation of wide swaths of paved surfaces before anyone could measure the difference in temperature between urban areas and their surrounding wilds. It took the drying of wells and the rapid deterioration of surface water quality before we could understand that soils provide natural water filtration, capable of transforming impurities in contaminated surface water into healthy groundwater reserves and stream flows.

The density and infrastructure needs of urban centres make a complete transition to green infrastructure solutions challenging with today's technology and materials. However GI systems can be strategically and successfully incorporated into existing grey infrastructure systems such as roads, buildings, cisterns, and sewers to augment the services provided by these traditional infrastructure systems. Green infrastructure implementation uses public spaces to greater effect in order to better serve communities and their surrounding environment and GI systems can also be the existing natural areas that provide services to communities which previously may have gone unnoticed. Recognizing these services can help protect these areas and prevent the need for grey infrastructures to replace the services that are lost by damaging them.

The increasing interest in green infrastructure systems has been driven by a variety of issues largely caused by urbanization and the corresponding loss of natural spaces due to conventional development. The concept of a "grey-to-green" transition to describe the growing interest in green infrastructure is helpful to describe the mindset needed for green infrastructure in urban and suburban environments to dismantle or augment hardscape surfaces to make room for natural systems that mitigate for the negative impacts of grey infrastructure impermeability. To date, green infrastructure systems are frequently used to support rather than supplant conventional grey infrastructure, however, the grey-to-green transition represents a shift in how governments at all levels see and manage for the community's assets and priorities as much as it does a physical transformation of human-occupied spaces. It is the result of a growing recognition that green infrastructure systems have the capacity to replicate and/or augment the services that nature provides and help solve the issues exacerbated by our continued urbanization and the impacts of climate change. It is important to note that while in heavily developed cities, green infrastructure tends to focus on addressing issues related to conventional infrastructure, developing cities and suburban cities may be able to avoid the unintended impacts of widespread grey infrastructure by ensuring that urbanization is informed by a green infrastructure lens to support strategic infrastructure investments that are able to manage capital costs, minimize impacts to the urban natural areas, while also continuing to provide the necessary municipal services.

How Green and Grey Infrastructure Can Work Together

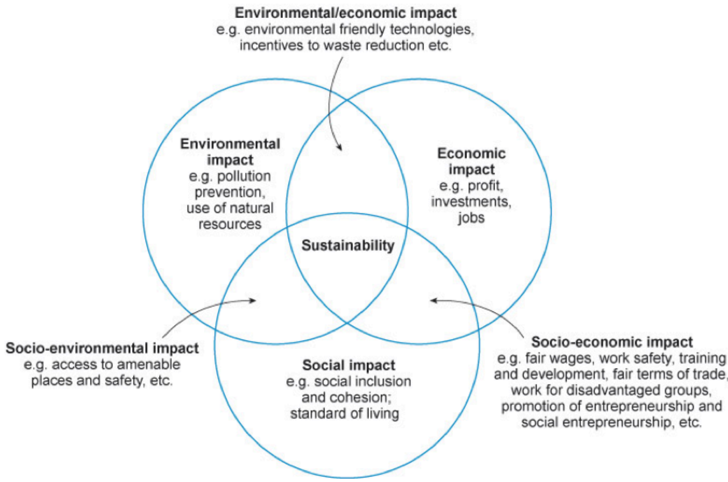
SERVICE	GRAY INFRASTRUCTURE COMPONENTS	EXAMPLES OF GREEN INFRASTRUCTURE COMPONENTS AND THEIR FUNCTION
Water supply and sanitation	Reservoirs, treatment plants, pipe network	**Watersheds:** Improve source water quality and thereby reduce treatment requirements **Wetlands:** Filter wastewater effluent and thereby reduce wastewater treatment requirements
Hydropower	Reservoirs and power plants	**Watersheds:** Reduce sediment inflows and extend life of reservoirs and power plants
Coastal flood protection	Embankments, groynes, sluice gates	**Mangrove forests:** Decrease wave energy and storm surges and thereby reduce embankment requirements
Urban flood management	Storm drains, pumps, outfalls	**Urban flood retention areas:** Store stormwater and thereby reduce drain and pump requirements
River flood management	Embankments, sluice gates, pump stations	**River floodplains:** Store flood waters and thereby reduce embankment requirements
Agriculture irrigation and drainage	Barrages/dams, irrigation and drainage canals	**Agricultural soils:** Increase soil water storage capacity and reduce irrigation requirements

From: "Browder, Greg; Ozment, Suzanne; Rehberger Bescos, Irene; Gartner, Todd; Lange, Glenn-Marie. 2019.

Integrating Green and Gray : Creating Next Generation Infrastructure. Washington, DC: World Bank and World Resources Institute. © World Bank and World Resources Institute. https://openknowledge.worldbank.org/handle/10986/31430 License: CC BY 4.0."

To date, green infrastructure systems are most frequently designed for stormwater management, which are provided by retaining and filtering rainwater at its source via the use of parks, urban forests, recreation areas, and swales (Haghighatafshar et al., 2018). There are many types of GI that provide multiple value-add benefits such as forests, flood plains, wetlands, and reefs that exist around cities and semi-natural systems including rain gardens and green roofs that exist within cities (Bartesaghi Koc, Osmond, & Peters, 2017). Urban green space provides multiple ecosystem services such as regulating temperatures during extreme heat events, improved air quality, providing human health benefits (e.g., physical activity), and mental well being (Obradovitch, 2018). The green infrastructure benefits described above are also essential in supporting cities in their efforts to adapt to a changing climate (e.g., mitigating the anticipated increase in extreme flooding events, water security/augmentation, extreme heat days and vegetation shading vs entire reliance upon air conditioning to name a few). The transition from grey to green infrastructure represents an expansion and added sophistication of municipal infrastructure priorities. The conventional responsibilities of facilitating transportation and the movement of goods and people, 'waste' removal, and flood prevention, will continue to be priorities for municipal governments. The employment of green infrastructure expands municipal infrastructure options while also improving water management, maintaining the integrity of the natural ecosystems, improving urban livability, and enhancing climate resilience. Planning justifications for green infrastructure are greatly improved by the use of triple bottom line analysis, which accounts for the economic, environmental and social impacts of infrastructure alternatives.

Triple Bottom Line Benefits of GI.



Source: This image is licensed under CC BY-SA 4.0 by The Open University.

Water Management

A significant focus of GI to date has been the management of urban stormwater. This focus is reasonable in light of the now known impacts of our over reliance on grey infrastructure and the increasing impacts of climate change, for which the grey infrastructure of the twentieth century was not designed. GI has the capacity to augment these aging systems. For example, natural assets such as urban and suburban forests, managed with their ecological integrity in mind, are highly effective at reducing surface runoff (retaining 85-95% onsite) due to the high interception of tree canopies and storage capacity in forest soils (Gill et al., 2007; Gunnell et al., 2019). Other engineered GI systems like green roofs, bio-retention cells, and permeable pavements can reduce stormwater runoff and flooding in dense urban areas (Dong et al., 2017) with effective systems retaining 50-70 % of stormwater onsite (Demuzere et al. 2014). However, the capacity to deal with heavy rainfall events is most limited for engineered GI like green roofs and permeable pavements, which have less surface area to intercept and absorb rainfall compared to naturally vegetated areas (Gill et al. 2007). These engineered systems also can degrade with use over time and require regular maintenance to ensure performance (Selarno et al., 2018). Integrated systems of grey (e.g. pipes and concrete gutters) and green infrastructure provide the greatest resilience to urban flooding. GI appears to be most effective when used throughout the upper portions of a drainage basin, reducing flows to low-lying areas by up to 70% even during extreme rainfall events (Haghighatafshar et al., 2018; Gunnell et al., 2019). Reducing runoff with GI can decrease the likelihood of combined sewer overflows (Selarno et al., 2018) and further improve water quality by trapping surface pollutants in soils and plant tissue where they can be broken down over time or removed if necessary (Demuzere et al. 2014).

Ecosystem Health

There is a growing recognition that ecosystems have inherent value (i.e., value in and of itself; not only as a service to humanity). Fostering biological diversity in human inhabited areas should not require additional justification. However, in most areas around the globe and throughout most of human history, inherent ecosystem inherent value has not figured prominently (or at all) in infrastructure decision-making and investments. Conventional economics plays into the increasingly high dollar value of land in urban areas, rendering the capacity to quantify the true economic (triple bottom line) value provided by natural assets essential to its justification and the expansion and preservation of natural systems in human-occupied environments. This is particularly important in the context of climate change and the ongoing mass extinction that has accompanied global urbanization. The literature reviewed for this course largely concludes that investments in natural assets can provide significant improvements to ecosystem health within and surrounding urban areas. However uncertainty remains as to how much investment is required, where the investment should be directed, and how to calculate the influence and impact of GI investments on ecosystem health and productivity.

Urban Livability

An important factor about green infrastructure that is often overlooked (or simply not known) by municipalities is its capacity to improve the health and wellness of its residents and enhance the attractiveness of the community. The presence of green spaces in urban areas has been shown to yield a surprising number of community benefits for residents; improvements to health and self-reported happiness and feelings of wellness, along with reductions in crime and poverty (Burley, 2018; Dunn, 2010). The reasons behind these connections are only beginning to be quantified in academic studies but are easily intuited. Access to nature and natural spaces are an important part of being human. Natural areas provide improved air quality and space for physical activity, but they are also essential to feeling connected to nature and can also enable residents to feel connected with their broader communities. Public green spaces also provide cool, shaded outdoor meeting places on hot summer days, and places of solace and privacy for those who may not have it elsewhere. These public areas can also lead to feelings of mutual accountability within the community for the care and maintenance of these natural spaces, as all residents benefit from their use. Green Infrastructure implementation can also help address some of the important racial and economic inequities common in urban areas. In cities around the world, areas with higher concentrations of visible minorities and lower income people are far more likely to have poor access to green space and poorly maintained public infrastructure. These conditions contribute to lower home values, worse health outcomes, and continued marginalization and poverty. Green Infrastructure can help address each of these historical inequities (Schell, 2020).

Temperature Moderation

Urban green spaces moderate temperature by providing evaporative cooling and shading from trees (Demuzere et al., 2014; Sun & Chen, 2017). This temperature moderation improves thermal comfort of urban residents and, combined with the added insulation of green roofs and green walls, can lower building energy use. Studies have illustrated that GI can, through strategic planting and maintenance, reduce heat-related deaths during extreme heatwaves through heat moderation of homes and entire residential areas (Demuzere et al., 2014). Dong et al (2018). Natural areas with mature trees provide significant cooling benefits, providing upwards of 10^{o}C cooling effect compared to neighbouring areas in urban centres during extreme heat events (Gill et al, 2007). Though localized in benefit, trees can be complimented by other forms of GI such as bodies of water (GI; both engineered and natural), and manufactured shelter structures. (Sun & Chen, 2017). Green roofs may also augment green space access, especially in areas where the entrenched urban structure disallows for green space expansion/creation. Green roofs can help make up for a lack of parks and open space in high-density urban cores. Gill et al. (2007) show that greening all roofs in town centers of Manchester could reduce maximum surface temperatures by 6.6^{o}C from current conditions and effectively counteract the projected rise in temperatures by the 2050s.

Climate Change Resilience

Each of the green infrastructure benefits described above improves community resilience to the impacts of climate change. Green infrastructure (GI) has been identified by UN-Water and the Intergovernmental Panel on Climate Change (IPCC) as essential to climate change adaptivity, enabling and supporting community resiliency, and promoting global water security, yet advances strategic and deliberate integration of GI into municipal infrastructure systems is uneven (Browder et. al., 2019; Revi et. al., 2014, Matthews, 2015). Climate change is expected to change weather patterns in a variety of ways; primarily exaggerating seasonal weather systems and the manifestations of these. Increased frequency and intensity of storms will pose challenges for managing stormwater flows and surface flooding (Collins et al., 2013). Extreme heat and drought are expected to become more common and will worsen the impacts of the urban heat island effect and further strain potable water supplies, especially in rapidly growing cities. Coastal communities will continue to incur and need to respond to sea-level rise (SLR), with specific emphasis on the potential displacement of hundreds of millions of people (Wong et al., 2014; de Jong et al., 2002; Valiela, 2006; McGranahan et al., 2007). Without strategic and deliberate actions to address community resilience, these conditions are likely to overwhelm existing urban infrastructure leading to extensive damage and loss of community infrastructure, increased public health risks, and negative impacts to social equity (Demuzere et al., 2014). Green infrastructure is effectively being employed around the world to fortify shorelines from sea-level rise, restore urban and exurban ecosystems, provide cool relief in urban areas, protect from drought and floods, and improve the physical and mental well-being of residents. The connections between green infrastructure and climate change resilience are discussed additional modules in the course.

Equity

Social Justice is another important lens through which to view green infrastructure and in the video clip provided, you will hear from the remarkable researcher/scholar Christopher Schell who speaks of the interplay between natural and human systems and the importance of looking at where trees and green spaces are located in urban centres. Be sure to watch this presentation (it is the closing keynote of the Puget Sound Infrastructure series). Pay attention to what Schell means when he says, “follow the trees.”

Learning Activities

- After viewing the video on GI and Social Justice, take some time to consider where the green spaces are located in your own neighbourhood. Draw a simple map of the area and highlight where the gray and green spaces are located. On the discussion board, **post your map of the green and grey spaces in your neighbourhood and consider what it means to “follow the trees” when it comes to equity and GI.**

Discussion Questions

- After reading the articles and viewing the two videos for this module, what do you think are the most compelling reasons for an urban centre to expand Green Infrastructure systems? Provide an example from the readings and one from your own jurisdiction.
- Share the map of a neighbourhood in the city where you live showing where that indicates where the grey and green spaces are located.

Readings & Resources

Readings

- **Blue and Green Cities: Blue-Green Infrastructure in Managing Urban Water Resources** (pg. xvii – pg. 17) (Note: this book is copyrighted but these pages are available as a free preview on Google Books).
- **Integrating Green and Gray (World Bank, 2018):**
    - Why Integrate Green and Gray Infrastructure (pg. 13-27)
- **EPA Green Infrastructure Case Studies**
    - Common Drivers and Regulatory Framework (pg. 7-10)
- **Handbook on Green Infrastructure Planning, Design, and Implementation**
    - Chapter 1 – Green Infrastructure and Health (Note: this book is copyrighted but this chapter is available as a free preview on Google Books).

Videos

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=30

Puget Sound Green Infrastructure Series: Closing Keynote – by Christopher J. Schell (Schell, 2020) – GI and Justice (Watch from 45m-1h3m)

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=30

Additional Resources and Citations

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- Samora-Arvela, A., Ferrão, J., Ferreira, J., Panagopoulos, T., & Vaz, E. (2017). Green Infrastructure, Climate Change and Spatial Planning:Learning Lessons Across Borders. *Journal of Spatial and Organizational Dynamics*, *5*(3), 13.
- Sun, R., & Chen, L. (2017). Effects of green space dynamics on urban heat islands: Mitigation and diversification. *Ecosystem Services*, *23*, 38–46. https://doi.org/10.1016/j.ecoser.2016.11.011
- Moore, T. L., Gulliver, J. S., Stack, L., & Simpson, M. H. (2016). Stormwater management and climate change: Vulnerability and capacity for adaptation in urban and suburban contexts. Climatic Change, 138(3–4), 491–504. https://doi.org/10.1007/s10584-016-1766-2
- Burley, B. (2018). Green infrastructure and violence: Do new street trees mitigate violent crime? Health & Place, 54, 43–49. https://doi.org/10.1016/j.healthplace.2018.08.015
- Siting Green Infrastructure: Legal and Policy Solutions to Alleviate Urban Poverty and Promote Healthy Communities (Dunn, 2010)
- Landscape Urbanism and Green Infrastructure (Public Green Infrastructure Contributes to City Livability: A Systematic Quantitative Overview – pg. 22-48) (Full book available to read on Google Books)

Module 3: Leaders and Lessons of Green Infrastructure in Practice

Learning Objective

- Cite the factors that contribute to the success of a city's efforts to implement green infrastructure by exploring methods used to employ and maintain green infrastructure and mitigate potential risks associated with its implementation.

GI exists in all cities to some degree, depending upon factors such as level of investment, protection of existing natural areas, adherence to engineering and planning standards, cultural and traditional designs that are reflected in the infrastructure, and geographical citing of urban centres. In many cases GI success and the benefits ecosystem services provide can be attributed to greater investment from the public and private sector. However, there are many factors that contribute to GI implementation success that are not dependent on significant levels of monetary resources. This module explores how cities around the world have made the most of the resources available to them to reap the greatest benefit from their GI systems.

The new technical terminology used to define modern green infrastructure belies an important truth: green infrastructure systems are often reminiscent of old solutions to familiar problems. Green (i.e. made of living things) infrastructure was the foundation of every successful pre-industrial human society. As early as 5000 BC, human societies used natural systems to try to stabilize their environments to help support larger concentrations of people. The ancient Egyptians were dependent on large floodable landscapes and shaded irrigation systems to manage the ebb and flow of the Nile. In the 1100s, the Khmer empire used vegetated channels to create irrigation works that survive to this day at sites like Angkor Wat. In the 1600s, the Dutch created living dikes that held rising seas at bay and contributed to their rise as a global sea power. Ancient empires often collapsed when they could no longer maintain the green infrastructure systems that supported them (Diamond, 2005).

The Dutch continue to proficiently mitigate sea level rise by adapting their traditional infrastructure systems to solve new challenges. Dutch green infrastructure has roots in the founding of their nation. Levies, dikes, and canals have enabled Dutch society. Today the Dutch systems are informed by modern science and technology to optimise the strengths inherent in living systems: adaptability, expansion and/or contraction, and durability/resiliency. Only after extensive deforestation and infrastructure failures did the Netherlands realize the indispensability of street trees to the stability of their canals and adjacent building foundations. These lessons have been learned through trial and error; invaluable lessons to be learned, adapted to and applied in other jurisdictions.

Cities that succeed in implementing GI do so because they acknowledge and account for the benefits that GI provides which traditional infrastructure does not. When the additional benefits of green infrastructure are accounted for, the case for integrating GI makes sense. Cities in the Pacific Northwest such as Portland, Oregon, Seattle, Washington and Vancouver, British Columbia have begun to plan and account for green infrastructure benefits beyond stormwater management such as improved urban livability, healthier ecosystems and low carbon resilience. Accounting for these additional benefits has helped redirect municipal resources towards green infrastructure development.

While New York City is famous for its wealth, it is infamous for its lack of space and its dense, narrow boulevards. Motivated by the need to reduce combined sewer overflows, the streets of New York City have undergone a rapid greening by streamlining the design and approval process for roadside green infrastructure systems. New York City created a thorough manual of standard GI designs that could be replicated throughout the city at relatively low cost. By utilizing economies of scale, the New York City Department of Environment reduced the material and labour costs of GI implementation and managed to install thousands of roadside bioretention systems in less than five years.

In Ontario, major flooding in the 1950s led to the creation of Conservation Authorities charged with managing and protecting watersheds to help protect communities and preserve local ecology. The Conservation Authorities are organized by watershed and work in partnership with all levels of governments and local communities. Their mandate is to protect life and property from water-related hazards and develop and maintain programs to conserve natural resources. The Conservation Authorities have the power to set standards and guidelines for development proposals in their jurisdictions and provide resources to member municipalities on how and where to implement green infrastructure systems. Two conservation authorities in particular, the Toronto Region

Conservation Authority and the Credit Valley Conservation Authority, have become national leaders in green infrastructure research and development.

Learning Activities

- Select one of the three city cases – Copenhagen, Portland or New York – and create a one page summary of GI motivations including the risks are they mitigating? What are the strategies, policies and identified benefits for that city? Do your own desk top research as well.

Discussion Questions

- After reading the chapter on Best Practice in Blue Green Cities and reflecting on your City case, cite what you consider are the key factors that contribute to the success of a city's efforts to implement green infrastructure.

Readings & Resources

Readings

- EPA Green Infrastructure Guide
- Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water Journal, 12(7), 525–542. https://doi.org/10.1080/1573062x.2014.916314
- Blue and Green Cities:
    - Blue-Green Infrastructure in Managing Urban Water Resources (pg. 291-301) (Note: this book is copyrighted).
- City of Portland – GI and Health Guide (p.4-22)
- Portland GI approach to both stormwater and wastewater in a highly urbanized mixed use neighbourhood called Hassalo and 8th designed by Biohabitats.The video is available for your viewing pleasure at https://vimeo.com/421179074

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- Blue and Green Cities
  - New York City – Becoming a Blue-Green City
  - Copenhagen – Becoming a Green Blue City
- Right-of-way Green Infrastructure
- City of Vancouver. (2019). 2019 Rain City Strategy [City Standards]. City of Vancouver: Green Infrastructure Implementation Team.(pg. 1-14)

Videos

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=37

Vancouver's Rain City Strategy – 4 min – (This video provides a brief introductory snapshot to GI in Vancouver and includes interview of folks dealing with rainwater management on both public and private property)

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=37

Additional Resources and Citations

- Winch, R., Clough, J., Mant, A., Hamilton – Russell, E., Barker, A., Payne, S., Gilchrist, A., Tantanasi, I., Clay, G., & Rothwell, J. (2020). Making the case for green infrastructure: Lessons from best practice. UK Green Building Council. http://eprints.whiterose.ac.uk/156025/8/08635_Making_the_Case_for_GI_FINAL__Web_.pd

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- Credit Valley Conservation Low Impact Development Guidance Documents
- Gunnell, K., Mulligan, M., Francis, R. A., & Hole, D. G. (2019). Evaluating natural infrastructure for flood management within the watersheds of selected global cities. *Science of The Total Environment*, *670*, 411–424. https://doi.org/10.1016/j.scitotenv.2019.03.212
- Haghighatafshar, S., Nordlöf, B., Roldin, M., Gustafsson, L.-G., la Cour Jansen, J., & Jönsson, K. (2018). Efficiency of blue-green stormwater retrofits for flood mitigation – Conclusions drawn from a case study in Malmö, Sweden. *Journal of Environmental Management*, *207*, 60–69. https://doi.org/10.1016/j.jenvman.2017.11.018
- Samora-Arvela, A., Ferrão, J., Ferreira, J., Panagopoulos, T., & Vaz, E. (2017). Green Infrastructure, Climate Change and Spatial Planning: Learning Lessons Across Borders. *Journal of Spatial and Organizational Dynamics*, *5*(3), 13.
- VIDEO: Philadelphia's Green Infrastructure Program – 2.5min

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=37

- Handbook on Green Infrastructure Planning, Design, and Implementation
    - Multifunctional Green Infrastructure: A Typology (pg. 227-242)

Module 4: Design Principles of GI

Learning Objective

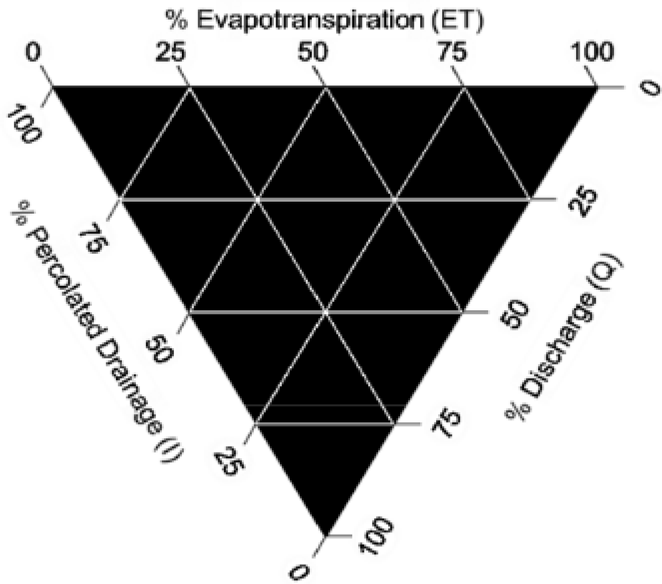
- Identify the basic design principles that make GI work and how design can inform site locations for GI

Green Infrastructure systems rely on a number of environmental and operational principles to provide the broad array of services. These principles, along with the science, engineering, and materials needed to harness them for effective green infrastructure, are well-established. However, they continue to be updated and refined in response to research studies, municipal experiences, and technical innovations. In this module you will explore the current state of green infrastructure science: what is known, what is still being studied, and what the implications are for GI design and planning.

Stormwater management is a significant motivation for GI implementation. In most urban and suburban areas, rainfall flows quickly along hard surfaces and enters the storm sewer system within five to 10 minutes. This short lag time between the rate of rainfall and the rate of sewer flow means that periods of intense (i.e. peak) rainfall inevitably lead to periods of intense sewer flow that may exceed the capacity of municipal sewers, leading to flooding and combined sewer overflows. The process of slowing water down so it does not quickly enter storm sewers is referred to as peak flow reduction. GI systems that aim to reduce the peak flow into municipal sewers have two primary components: storage capacity and discharge control. Green Infrastructure storage capacity holds rainfall onsite before it can enter the storm sewer system, increasing the time that it takes for rainfall to turn into sewer flow. This storage can be provided in soil, gravel, and may include above-ground and below-ground components. For GI systems to drain properly and retain capacity for future storm events, a discharge path must be designed to drain the system within a time frame deemed acceptable by city planners and policy-makers (usually between 12 and 48 hrs). This time-period is referred to as the maximum drawdown time.

The Water Budget Table is a tool intended as a visual indicator of the distribution of mass outflow among event runoff (Q), evapotranspiration (ET) and percolated or stored drainage (I). You will read about this in the article by Eger et al.

Water Budget Triangle



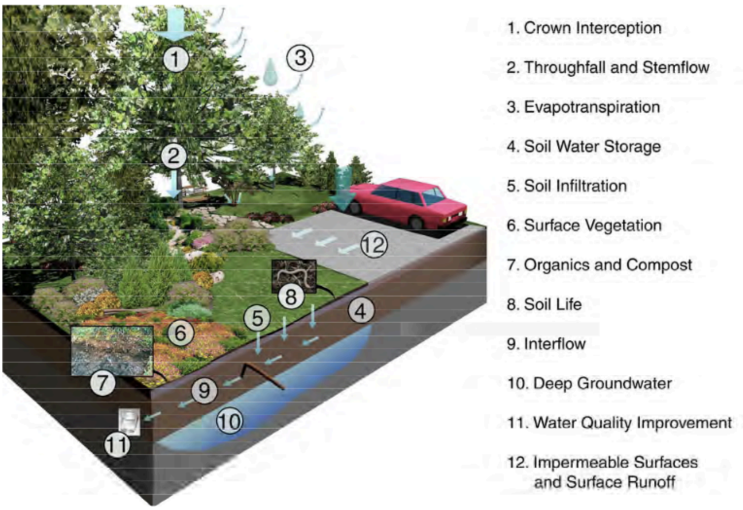
Source: Page 2 of https://www.researchgate.net/publication/286426965_Water_Budget_Triangle_A_New_Conceptual_Framework_for_Comparison_of_Green_and_Gray_Infrastructure

Water can leave a GI system through several pathways. GI systems may be designed to infiltrate a portion of rainfall into groundwater reserves in order to replenish depleted groundwater reserves and improve regional water security. When the underlying soil cannot infiltrate fast enough to drain the system, a perforated underdrain may be installed at the bottom of a GI system to slowly drain saturated soil layers. The vegetated components of GI turn some rainfall into water vapour through evapotranspiration. Once the surface and subsurface storage capacity of a GI system is full, an overflow pathway should be designed to ensure that excess water spills into the existing storm sewers and not into homes and businesses. Establishing infiltration rates and evapotranspiration rates is an essential part of GI design. There are a variety of technical procedures and scientific equations used for establishing these variables. Municipalities that adopt a single standard for determining them can decrease the design costs for developers and the review burden for municipalities.

Source Control

Just as rainfall hits all areas of a development site, the design of stormwater source controls should be integrated with the entire development concept. The Metro Vancouver Source Control Guidelines document in your readingsoutlines a design process for stormwater source control practices – identifying key steps and their arrangement in a typical development process. This document is used widely in the Metro Vancouver area.

Stormwater Variables of Absorbent Landscapes



Source: Stormwater Source Control Design Guidelines, page 2-1

GI systems are increasingly being used to prioritize a specific performance outcome. Where heat island reduction is a priority, plants with high evapotranspiration rates may be used to shed heat from the surrounding area. Where infiltration is a priority, systems can be designed to maximize their underground surface area or can use sandy soils with high infiltration rates. If a system is intended to maximize peak flow reduction, additional surface storage (through increased area or depth) can be provided to hold more rainfall onsite. GI systems that aim to improve water quality rely on bioretention or biofiltration to trap pollutants in soil and absorb pollutants into the systems biomass. Plant selection can be used to target specific pollutants of concern. Bioretention relies on a number of mechanisms to remove pollutants: volatilization, sedimentation, adsorption, absorption, microbial action, plant resistance and uptake, and filtration. Bioretention pollutant removal can also be targeted towards specific pollutants of concern by using soil amendments shown to improve desired outcomes. The mechanisms of pollutant removal and the soil amendments used to supplement them, are described further in the supporting images of this module (Mangangka et al, 2015). Cities such as Vancouver, Ottawa, and Portland are also using city GIS data to incorporate other variables into GI design and planning decisions, such as the absence of existing green spaces or the compatibility of existing infrastructure constraints (Jolliet, 2019; Coutts, 2016; Dunn, 2010).

Planting is a significant dimension of GI and there is a great deal of knowledge about what works under what conditions. Plants are a natural form of pollutant removal. Numerous resources are available in the reading section that provide lessons learned, planting guides and other landscape related materials.

Pollutant Removal Mechanisms Used in GI Systems

Name	Mechanism
Volatilization	Evaporation of pollutant mechanisms
Sedimentation	Settlement of heavy particles
Adsorption	Attachment to water or soil particles
Absoprtion	Soaking deeper into groundwater
Microbial Action	Pollutants broken down by bacteria
Plant Resistance and Uptake	Plants absorb some pollutants into microbes
Filtration	Particles captured by a removable filter

Source: Stiffler, 2013., Table By Nick Mead-Fox

Another principle that municipalities and private firms often refer to when planning and implementing GI systems is the impervious to pervious (IP) ratio. The IP ratio is a ratio of the amount of impervious drainage area directed towards a given pervious green infrastructure area. This ratio can capture many aspects of GI design. It can account for erosion potential in the cell, volume retention, water quality improvements, and heat island reduction by setting the IP ratio to the most limiting performance variable. Many municipalities use an IP ratio to provide quick estimates of system sizing in a particular drainage area. A standard IP ratio depends on a standard design, as changes in GI design such as increased ponding depth or filter media depth can increase the acceptable impervious drainage area. By committing to a specific IP ratio, municipalities may not be accounting for the impact of design variations and consequently they can stymie GI innovation. However, a maximum IP ratio can also help ensure that green infrastructure systems are not undersized and that GI can serve the multiple purposes for which it should be designed. This is just one example of the difficulties in providing dependable guidelines to ensure GI systems perform well without tying the hands of designers and preventing them from pursuing innovations in a rapidly changing field.

The readings for this module will introduce you to the Water Budget Triangle, source control guidelines, as well and overview of key terms that describe how design principles are applied in GI. The short videos discuss the application of design principles in GI, demonstrate how bioretention operates and, for example, how a rooftop garden functions to capture and store rainwater. Be sure to view the video presentation by City of Vancouver Engineer, Rob Lukes who provides a detailed explanation of considerations and myths of bioretention design.

Learning Activities

- After reviewing the introduction to this module, the reading and videos, create a one page set of definitions for the following concepts:
    - Source Control
    - Biofiltration
    - Peak Flow Reduction
    - Infiltration
    - IP Ratios
    - Pollutant Removal Rates
    - Planting Materials in GI

Discussion Questions

- Imagine that your neighbour or colleague is curious about how GI works. What is one design principle from the list you have created that you would share with them and why? What questions remain for you about the the design principles of GI?

Readings and Resources

Readings

Recommended:

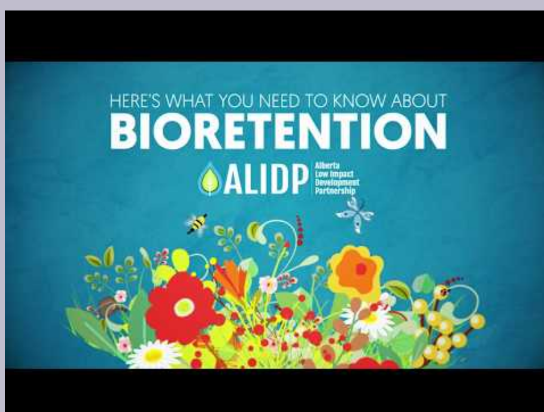
- Landscape Urbanism and Green Infrastructure (Assessing Stormwater Nutrient and Heavy Metal Plant Uptake in an Experimental Bioretention Pond – pg. 108-124) (Full book available to read on Google Books)
- Comparative Performance Assessment of Bioretention in Ontario – CVC (6 pages)
- International Stormwater Best Management Practices (BMP) Database Advanced Analysis: Influence of Design Parameters on Achievable Design Parameters: 1-10 https://doi.org/10.1061/(ASCE)EE.1943-7870.0000227
- Water Budget Triangle: A New Conceptual Framework for Comparison of Green and Gray Infrastructure
- Water Wise Planting Plan (West Coast of North American)

Optional Resources (if you have time):

- Credit Valley Conservation (Ontario) LID Landscape Design Guide
- Montgomery Country (suburb of Washington, DC, very progressive in their GI implementation) – Guide to Rain Garden Planting
- New York City – very prescriptive planting plans for GI in road ROWs. Starting at sheet GI-501A
- Designed plant communities – Phyto Studio

- Metro Vancouver Source Control Guidelines
  Very useful design guidance widely used within the region. Generally very good but oriented more towards suburban built forms. Currently being updated to modernize.

Videos:



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- Design Principles City of Vancouver Presentation by Robb Lukes, P.Eng.

Module 5: Guidelines, Targets and Incentives

Learning Objective

- Examine the guidelines, targets and incentives used by municipal governments to guide GI design and implementation.

This module explores further how guidelines, targets and incentives are used by municipalities to regulate and stimulate the implementation of green infrastructure. Guidelines and targets are used to communicate the desired outcomes of GI systems and the acceptable means of reaching them. Incentives include: stormwater fee discounts; development incentives; rebates and financing; and awards and recognition.

The guidelines and targets adopted by a municipality often represent a balance between the goals of a municipality and their will, capacity and resources to meet those goals and they can vary greatly between municipalities. Contextual factors such as climatic conditions, local ecological resources and the purpose of the system being designed also have important considerations. As well, guidelines and targets are dependent on institutional factors such as the level of commitment of the governing bodies that set these regulations and the capacity of their workforces to carry them out.

Targets and guidelines represent two distinct regulatory tactics common to most engineering disciplines. Targets refer to quantitative or qualitative performance goals of individual GI systems that are designed to help address whatever factors motivate a municipalities grey-to-green transition. Targets are prescriptive in the sense that a designer will have to demonstrate using established monitoring data or best practices that a proposed GI system will provide the level of service that the target requires. However targets can also be flexible means of regulation that allow designers the freedom to create systems as they see fit, as long as they meet the performance target. Guidelines refer to the approved best practices for designing GI systems in a particular municipality. Guidelines can represent a flexible form of regulation that can be superseded when context or innovation require. Many municipalities will accept designs that are not in line with their adopted engineering guidelines if the proponent can demonstrate the system is safe and effective, however the approval process for designs that fall outside approved guidelines is often prohibitively long and expensive. When municipalities go to the effort of reviewing and adopting an engineering design guideline for a specific system, it can make them less inclined to approve systems that vary from that guidance.

In Ontario, the Conservation Authorities offer guidelines to developers and municipalities on green infrastructure best practices for design, installation, and maintenance. These guidelines are outlined in the STEP Low Impact Development Stormwater Management Planning and Design Guide included in the Additional Resources section. While the Conservation Authorities have development approval authority for development applications near waterways, the guidelines they produce are only suggestions on how to receive their approval within theses areas. Municipalities within the Conservation Authorities watershed are under no obligation to adopt these recommendations as their own binding standards for development proposals. In contrast, New York City has adopted a broad and comprehensive set of standards for GI implementation that apply everywhere within city limits. These standards are outlined in their 2020 document, *Standard Designs and Guidelines for Green Infrastructure Practice* included in the Additional Resources section.

In November 2019 the City of Vancouver set a target for new developments to capture and clean 48mm of rainfall over 24 hours. In contrast, Toronto municipalities are facing difficulties in implementing a capture target of less than 29mm. Upon adopting the 48mm target, the City of Vancouver had few approved GI standards in place which would allow engineers and developers to meet it. The target is intentionally aspirational and relatively open-ended. It has been adopted to spur GI implementation and accelerate the adoption of the regulations and standards required to ensure the efficacy of these systems. The City intends to create a set of adaptable regulatory guidelines that are better suited to accommodating the relatively rapid rate of change in GI best practices and technologies. City of Vancouver will also require new developments to control post-development flows to pre-development flows based on a post-development IDF curve for the year 2100 to account for additional rainfall due to climate change. If these new standards are successfully implemented, the City of Vancouver will be a global leader in sustainable rainwater management and an example to other municipalities pursuing grey-to-green infrastructure transitions.

Learning Activities

- Drawing on the examples provided in your readings, list at least two guidelines and one incentive that you believe would help GI address issues in your own municipality. Consider the advantages and disadvantages of these guidelines as suggestions rather that enforceable regulations. 500 words max. Upload your paper for feedback.

Discussion Question

- Based on your reading, discuss how federal guidelines and targets have influenced GI implementation in New York City

Readings & Resources

Readings

- EPA Green Infrastructure Guide
    - Menu of Local Green Infrastructure

Policies – pg. 13-23

Videos

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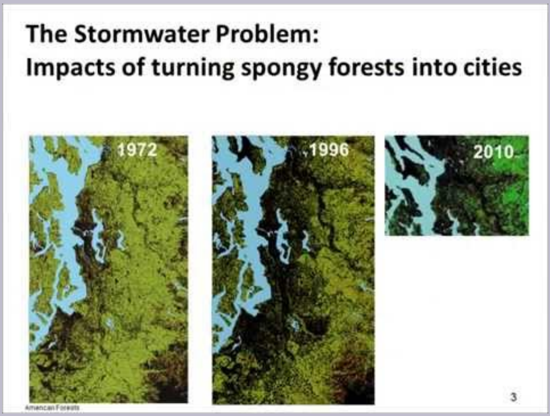
Additional Resources and Citations



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A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=44

- Minnesota Stormwater Manual – Simple Method for Phosphorus Loading and Removal
- STEP Low Impact Development Stormwater Management Planning and Design Guide
- New York City Stormwater Manual
- New York City Standard Designs and Guidelines for Green Infrastructure
- San Francisco Stormwater Control Plan Materials
- Integrating Green and Gray (World Bank, 2018): Why Integrate Green and Gray Infrastructure
    - Improving Service Delivery with Green

Infrastructure: pg. 27-41

- Sage, J., Berthier, E., & Gromaire, M.-C. (2015). Stormwater Management Criteria for On-Site Pollution Control: A Comparative Assessment of International Practices. Environmental Management, 56(1), 66–80. https://doi.org/10.1007/s00267-015-0485-1

Module 6: GI and Building Resilience For Climate Change

Learning Objective

- Identify the mechanisms by which GI can improve climate resilience and adaptability and discuss examples of best practices.

All municipal infrastructure is designed using statistical projections of likely weather patterns. To make a building or a bridge safe from floods you need to know how high the surrounding water may rise. To build a reservoir and a dam you need to know how much water will flow into it and how much water you need. To design a sewer well you need to know that it will not flood during an average spring storm. As climate change leads to changes in precipitation rates and depths around the world, infrastructure designed for the 20th century will become obsolete. Cities that construct infrastructure pre-emptively, with projections of rainfall and heat, may end up spending too much on oversized systems. Or focus on the wrong issue altogether; planning for drought, when they should have been protecting from floods. Even the best global climate models (GCMs) acknowledge margins of error that represent trillions of dollars in infrastructure over the next hundred years.

Whether cities attempt to plan for a projected climate future or rebuild after failure, an unprecedented global reconstruction of infrastructure is likely at hand. This reconstruction is an opportunity to rethink how cities work and what they can provide for the growing number of people that call them home. Planning for this reconstruction well requires adaptable infrastructure designed not for a measured "what-has-been" but for a feasible range of "what-could-be". This is green infrastructure's greatest potential; a capacity for resilience that could help fortify cities against climate uncertainty while also reducing the emissions associated with development. The combination of these benefits is captured by the term "Low-carbon resilience (LCR)" (ACT, 2018). LCR focuses on solutions that simultaneously decrease GHG emissions while improving system resilience to climate change impacts. GI is a common entry point for municipalities to begin accounting for LCR in their planning decisions. Green infrastructure is a LCR entry point for local governments because GI interventions avoid or reduce the use of carbon-intensive products like concrete and steel that define grey infrastructure and require less carbon intensive construction techniques, while also improving system resilience to impacts like flooding and extreme heat temperatures. GI systems can also absorb carbon throughout their lifetime, potentially offsetting the emissions associated with their construction. A study of 28 U.S cities found that urban trees sequester an average of 2.05 t C ha^{-1} $year^{-1}$(Demuzere et al., 2014). With proper maintenance, GI systems can become more effective with age as plant communities grow and establish (Denjean et al., 2017).

Successful design of GI systems requires a thorough understanding of local environmental and ecological conditions to determine the potential rates of rainfall, infiltration and evapotranspiration. If available, downscaled climate models should be considered to assess how climate change may shift these variables in the future. Locally available flora should also be considered when determining evapotranspiration rates and potential rates of pollutant removal through adsorption or biotransformation. Locally available soils should be accounted for when determining the target drawdown times and infiltration rates of GI systems. Locally available grey infrastructure components that contribute to GI functionality, such as perforated pipes, overflow inlet grates, inspection chambers, and pipe cleanouts must also be assessed and sourced. Collecting and analyzing this environmental, ecological, and industrial data represents a significant challenge for budget-constrained municipalities.

For traditional infrastructure, municipal responsibility has worked well. It is relatively easy to transfer traditional grey infrastructure design principles from one region to another. Even when accounting for changing rainfall patterns and climatic conditions, grey infrastructure can be designed and installed based on a few fundamental principles that govern the performance of constructed systems like roads, sewers, and building. GI must be designed to accommodate local context because it utilizes living components such as vegetation, soil biota, and local fauna which are essential to GI performance and success. A GI system designed for southern Ontario will use vegetation and soil from that region which may not be available in Vancouver or suitable for Vancouver's climate. The living components of Green Infrastructure require each municipality to establish their own GI best practices that account for projected local impacts, existing vulnerabilities, and available ecological and biological resources.

Despite these challenges, resources are being developed around the world that other municipalities are learning from and using to decrease the burden of their own data collection. Municipalities pursuing GI are looking to cities within their ecological and climatic zones to coordinate on research projects and testing. For example, when selecting an appropriate soil for pollutant removal, municipalities can look to research undertaken elsewhere that uses soils with similar properties to those available locally (i.e. particle size distribution and organic content) to help inform the selection process.

In the context of climate change, physical system adaptability is defined by its capacity to handle the extremes that climate change may bring. The readings and other resources in this module provide insights and tools for discussing adaptation to climate change via GI and outline policies and practices that will require city leaders, in the language used in the Vancouver's Changing Shoreline report, to either resist, accommodate, move or provide a combination of all three strategies.

Learning Activities

Discussion Question

- In light of the climate risk assessment resources provided in this module, what are the risks that concern you most in the jurisdiction where you live and work and what arguments can be made to integrate GI into existing infrastructure to build in greater resilience?

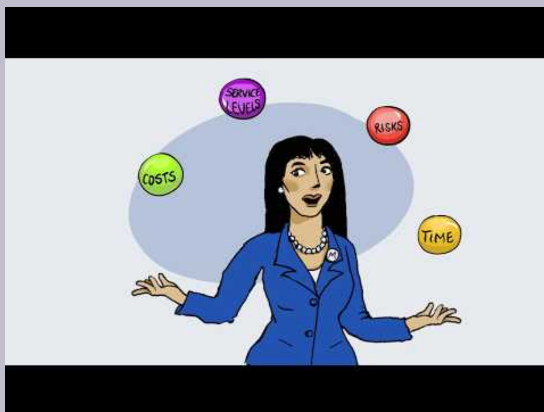
Readings & Resources

Readings

- Vancouver Greenest City Scholar report – resilient landscapes
- Ramyar, R., & Zarghami, E. (2017). Green Infrastructure Contribution for Climate Change Adaptation in Urban Landscape Context. Applied Ecology & Environmental Research, 15(3), 1193–1209. https://doi.org/10.15666/aeer/1503_11931209
- Vallejo, L., & Mullan, M. (2017). Climate-resilient infrastructure: Getting the policies right.https://doi.org/10.1787/02f74d61-en
- Vancouver's Changing Shoreline – Preparing for Sea Level Rise
- Enhancing Future Resilience in Urban Drainage System: Green versus Grey Infrastructure
- The role of science-policy interface in sustainable urban water transitions: Lessons from Rotterdam (2017)

Videos

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=46



A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=46

Additional Resources and Citations

- Childers, D. Cadenasso, M. Grove, M. Victoria Marshall, Brian Mcgrath, & Steward T. A. Pickett. (2015). An Ecology for Cities: A Transformational Nexus of Design and Ecology to Advance Climate Change Resilience and Urban Sustainability. Sustainability, 7(4), 3774–3791. https://doi.org/10.3390/su7043774
- Ching, L. (2016). Resilience to climate change events: The paradox of water (In)-security.

Sustainable Cities And Society, 27, 439–447. https://doi.org/10.1016/j.scs.2016.06.023

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- Mullan, M. (2018). Ecosystem-based approaches to adaptation: Compilation of information (Synthesis Report FCCC/SBSTA/2011/INF.8; OECD ENVIRONMENT POLICY PAPER NO. 14). OECD.
- Zahmatkesh Zahra, Karamouz Mohammad, Burian Steven J., Tavakol-Davani Hassan, & Goharian Erfan. (n.d.). LID Implementation to Mitigate Climate Change Impacts on Urban Runoff. World Environmental and Water Resources Congress 2014, 952–965. https://doi.org/10.1061/9780784413548.097
- Waterscape – Gulf Islands
- MNAI
- Combatting Canada's Rising Flood Costs: Natural infrastructure is an underutilized option
- North Perth Asset Management

Module 7: Green Infrastructure Governance

Learning Outcome

- Gain familiarity with decision-making for GI implementation in different municipalities and the professionals involved in the process.

The benefits of GI have been established in practice and in academic literature, yet not all urban centres have recognized its potential. Reasons for this relate to various factors; a lack of municipal capacity and technical expertise, the need for new regulatory requirements, uncertainty regarding industry capacity, unfamiliarity with related risks and opportunities, and conflicting goals and mandates of municipal departments and institutions (Tayouga, 2016; Dhakal, 2017; Young et. al., 2014). Addressing the uncertainties and obstacles to GI implementation is essential to ensuring that environmental damage from 20th century urbanization does not continue throughout the 21st.

Grey infrastructure systems have been the keystone of 20th century urbanization. For green infrastructure to become integrated as standard practice for urbanization in the 21st century, design principles and operating procedures must become as understood, reliable and accessible as those used for traditional grey infrastructure design. Transitioning towards new infrastructure typologies requires significant administrative resources, technical capacity, and political will. While climate change is a global phenomenon, the responsibility for managing its impacts will fall largely on the shoulders of regional and municipal governments. This module will explore the strategies and processes employed by municipalities, regions, and nations to govern green infrastructure and promote high-quality, successful systems. Case examples will be analyzed to explore both the determinants of success and the challenges that remain for successful GI governance.

As the Porse article suggests, "Governance typically describes rules for decision-making involving many stakeholders, including individuals, civic organizations, and government institutions, in the context of laws and policies. Governance is distinguished from governmental actions to recognize flexibility, decentralization, and inclusiveness of private and community participants, who may have established, extra-governmental processes for managing environmental resources."

To effectively implement GI, municipal policies and procedures must consider the additional challenges inherent to approving, maintaining, and expanding a publicly accessible and decentralized infrastructure grid. Changing institutions and policies related to infrastructure management involve changing the primary mode by which citizens and corporations interact with their municipal government. Successful GI governance requires top-down, lateral and bottom-up approaches depending upon the specific topic at hand and the target audiences being sought. As the primary managers of infrastructure systems, top-down directives from governments will play a primary role, supported by the numerous non-government organizations that conduct the community outreach, secure community partners for pilot projects, etc. in addition to government agencies (i.e., Federation of Canadian Municipalities). GI success relies on the involvement and support of local citizen collaborations with government agencies, private sector developers and practitioners who are often the one's responsible for implementing and maintaining GI systems.

As this chart from Danish researchers suggests, governance innovations in GI implementation involve a spectrum of stakeholders leaders including NGOs, Citizens and Governments.

FIGURE 3: TYPOLOGY CHARACTERISING DIFFERENT KINDS OF ACTIVE CITIZENSHIP APPROACHES IN UGI GOVERNANCE

Governance model	*Active Citizenship approach*	*Description*
Non-Government led approaches	**Grassroots initiatives**	Relatively small scale initiatives, focused on a specific site, usually located on public or municipal land. Initiatives are normally started and maintained quite autonomously by local residents. Serve citizen and community objectives.
	Organisation initiated grassroots initiatives	NGOs or social enterprises mobilise active citizenship and community action. Usually conducted on public or municipal land, or on land with public access. There is power sharing between the organisation and citizens and there may be some coordination with municipalities. Serve citizen and community objectives. May serve strategic municipal objectives.
	Green Hubs	Experimental, creative coalitions of public and private organisations, social enterprises, businesses and citizens building networks and creating knowledges to develop UGI on public and private land that serves community and municipal objectives.
Co-governance	**Co-governance**	Partnerships between citizens or citizen organisations and municipalities with power being shared between those involved. Usually located on municipal land and may involve additional public assets. Sites may be large as well as small. Serves municipal as well as citizen and community objectives.
	Green Barter	Businesses develop and/or maintain green space in exchange for a formalised right to use the values of those spaces for business purposes and profits. May involve small as well as medium sized sites. Serves municipal as well as business objectives. May serve community objectives.
Government led processes and co-management	**Municipalities mobilising social capital**	Municipality led initiatives which invite grassroots and individual citizens to participate in strategic or site level actions, which may be about consultation and information sharing, involvement in planning, or contributions to management and maintenance (i.e. place keeping) of green spaces. Primarily serves municipal objectives, but also serves community and citizen objectives.

Source: Figure 3: Typology Characterising Different Kinds of Active Citizenship Approaches in UGI Governance is found on page 16 of Report on the Green Surge in Denmark, University of Copenhagen (2017).https://www.e-pages.dk/ku/1337/html5/

This module will look at three distinct governance regimes for green infrastructure implementation: centralized GI control in Singapore, federally motivated GI in New York City, and locally directed GI in Rotterdam. Each of these governance mechanisms has distinct strengths and weaknesses that will be explored in the readings and module discussions. In Singapore, centralized control has allowed for the quick implementation of a broad array of green infrastructure programs. Some of these programs are implemented at great expense, such as a program to cover 50% of rooftop greenery expenses. In Rotterdam, a series of floods and droughts has led to a comprehensive, city-led climate adaptation strategy that encourages experimentation to pursue customized solutions for local context. Each of these systems often require approval from multiple government agencies, requiring extensive cooperation between municipal agencies, private sector actors, and researchers. In New York City, frequent combined sewer overflows in violation of the federal Clean Waters Act have led to a focusing of resources towards water retention and quality improvements. To save costs and ensure high-performing systems, the City has created a suite of standardized designs and procedures that increase implementation rates but may also stymie innovative and adaptable designs. In the short term these changes have been useful however these very same measures may also inadvertently thwart innovative and adaptable GI designs.

Learning Activities

- After reviewing the video and reading the Porse article on goverance, select at least one of the two case studies and describe the array of GI Tools implemented, the range of policies to incentivize and regulate GI projects and the importance given to the role of partnerships – public-private, and community-based.

Discussion Questions

- Why might green infrastructure systems need different forms of governance than traditional infrastructure?
- How can governance regimes become more inclusive to the variety of stakeholders in green infrastructure?

Readings & Resources

Readings

- Porse, E. (2013). Stormwater Governance and Future Cities. Water (Basel), 5(1), 29–52. https://doi.org/10.3390/w5010029
- Blue and Green Cities
    - Rotterdam – Becoming a Blue-Green City
    - Singapore – Becoming a Blue-Green City

Videos

A Vimeo element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=48

Additional Resources and Citations

- Handbook on Green Infrastructure Planning, Design, and Implementation
    - The Governance and Management of Public Green Spaces – pg. 337-354

- Young, R. F., & McPherson, E. G. (2013). Governing metropolitan green infrastructure in the United States. Landscape and Urban Planning, 109(1), 67–75. https://doi.org/10.1016/j.landurbplan.2012.09.004
- Zhang, D., Gersberg, R. M., Ng, W. J., & Tan, S. K. (2017). Conventional and decentralized urban stormwater management: A comparison through case studies of Singapore and Berlin, Germany. Urban Water Journal, 14(2), 113–124. https://doi.org/10.1080/1573062X.2015.1076488

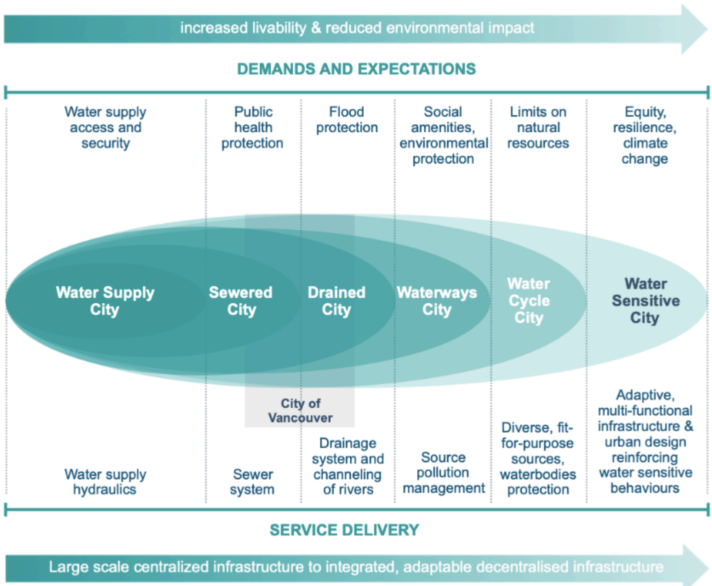
- Green Planning for Cities and Communities: Renaturing Cities
    - Green and Blue Urban Spaces as Paradigms for Urban Planning – pg. 43-67

Module 8: Planning Principles and Communicating GI Solutions

Learning Objectives

- GI Planning
- Communicating GI Solutions

Successfully integrating GI into urban planning, as we can see from the examples of the Cities of Vancouver and Rotterdam, requires adaptive management. Adaptive management for GI calls for "embedding water sensitive values, behaviours and design principles into city wide systems planning" e.g., sewer and drainage systems, transportation, parks and natural assets of the community. Taking into account the water cycle and the built environment, adaptive management is a form of planning that is flexible and responsive, as well as interdisciplinary — involving not only engineers, but architects, economists, urban designers, construction, citizens and even artists.



Source: URBAN WATER TRANSITION FRAMEWORK. Adapted from“ Urban Water Management in Cities” T.H.Wongetal, 2009, Water Science and Technology, 59(5), page 85.

As the ‘Making it Happen’ chapters explores green-to-grey integration, whether for stormwater management or urban cooling. This integration is not only connected to climate change adaptation; it is also concerned with enhancing ecological connectivity and protecting biodiversity. “A socially inclusive planning process might not guarantee a socially cohesive community – but it is an important step towards one.” As you can see from the matrix below, green infrastructure or urban green infrastructure (UGI) addresses urban challenges by applying the principles of integration, connectivity, multifunctionality and social inclusion.

LINKING UGI PRINCIPLES WITH URBAN CHALLENGES

	INTEGRATION	CONNECTIVITY	MULTIFUNCTIONALITY	SOCIAL INCLUSION
CLIMATE CHANGE	Green-grey measures for flood retention or urban cooling.	Connected green structures that enhance natural ventilation and cooling.	Regulating services that contribute to climate change adaptation as an integral part of planning for multifunctionality.	Inclusion of groups vulnerable to climate change impacts in UGI planning.
BIODIVERSITY	Habitat provision, supporting native plants as one of the co-benefits of green-grey solutions.	Networks for ecological connectivity.	Protecting ecological functions and habitat as an integral part of planning for multifunctionality.	Fostering awareness among all groups of the value of biodiversity.
GREEN ECONOMY	Reduced management costs through integrated green-grey systems; avoided costs through risk mitigation.	Promotion of sustainable transport systems, e.g., walking and biking to lessen environmental impacts.	Cost effective UGI solutions through providing multiple benefits in the same space.	Promotion of a green economy, through co-creation, co-management and co-governance of urban green spaces.
SOCIAL COHESION	Consideration of the usability and amenity values of integrated UGI measures to promote social cohesion.	Provision of equitable access to urban green spaces.	Provision of UGI to meet identified demands and needs of all groups.	Consideration of vulnerable and less-vocal groups' needs and their empowerment through collaborative planning.

The four core principles of UGI planning can each help to address a range of challenges, including those examined in GREEN SURGE.

Source: UGI Planning Guide

This module provides examples of municipalities that are creating new ways of communicating and encouraging green infrastructure solutions. From online technical design manuals to public outreach and volunteer programs, green infrastructure is motivating municipalities to rethink the opaque engineering manuals traditionally used for infrastructure management. And these approaches are being woven into urban planning practices.

In Ontario, the Sustainable Technologies Evaluation Program has developed a comprehensive online resource for GI professionals to easily access new information and changing best practices. In Minnesota, an ever-growing collection of green infrastructure guidance and resources led to the complete digitization of a traditionally hard copy document. The San Francisco Public Utilities Commission now has its Stormwater Control Plan guidance, GI calculators, background information and guidebooks, in a centrally available online database. (These resources are located in the Additional Readings tab).

Successful municipal planning for GI requires the understanding and support of local residents. The World Bank reading provides an international context for the ways that local communities are key to successful GI implementation. The Blue Green Cities chapter on best practices provides an overview of GI in municipalities. Key findings from the City of Vancouver's Rain City Strategy provide insight into how integration of GI works 'on the ground' and the projects funded by the Federation of Canadian Municipalities offer insights into a range of innovative GI projects.

Learning Activities

- Read the articles provided.
- Scan the additional readings

Discussion Question

- From your readings in this module or cases highlighted in past modules, what urban centre does an exceptional job at communicating the power and potential of urban green infrastructure because it integrates well with existing infrastructure, promotes connectivity and/or multifunctionality or fosters social inclusion?

Readings & Resources

Readings

- Integrating Green and Gray (World Bank, 2018):
    - Why Integrate Green and Gray Infrastructure – The Social Foundation of Green Infrastructure pg. 41-51
- Blue and Green Cities:
    - The Role of Blue-Green Infrastructure in Managing Urban Water Resources – Best Practices – pg. 291-303
- Green Planning for Cities and Communities:

- Renaturing Cities – 23 pages

- Urban Green Infrastructure Planning:

  - A Guide for Practitioners Making it Happen: pg. 43-55

- Core Principles of UGI Planning from EU GreenSurge Guide (pg.22-42)
- Review the funded projects for 2020 by The Green Municipal Fund (GMF) a $1-billion program funded by the Government of Canada and delivered by FCM.
- Vancouver Rain City Strategy – Key Findings (6 pages)

Additional Resources and Citations

- EPA – Overcoming Barriers to Green Infrastructure Implementation
- Shandas, V., Matsler, A. M., Caughman, L., & Harris, A. (2020). Towards the implementation of green stormwater infrastructure: Perspectives from municipal managers in the Pacific Northwest. Journal of Environmental Planning and Management, 63(6), 959–980.
- Tackling Barriers to Green Infrastructure: An Audit of Municipal Codes and Ordinances
- Minnesota Stormwater Management Resources
- Minnesota Stormwater Best Practices
- Minnesota Stormwater Manual
- University of Minnesota Watershed Game

- Lieberherr, E; Odom Green, O. (2018). Green Infrastructure through Citizen Stormwater Management: Policy Instruments, Participation and Engagement. Sustainability, 10(6), 2099. https://doi.org/10.3390/su10062099
- Wilker, J., Rusche, K., & Rymsa-Fitschen, C. (2016). Improving Participation in Green Infrastructure Planning. Planning Practice & Research, 31(3), 229–249. https://doi.org/10.1080/02697459.2016.1158065
- Dhakal, K. P., & Chevalier, L. R. (2017). Managing urban stormwater for urban sustainability: Barriers and policy solutions for green infrastructure application. Journal of Environmental Management, 203(Pt 1), 171–181.https://doi.org/10.1016/j.jenvman.2017.07.065
- Lennon, M. (2015). Green infrastructure and planning policy: A critical assessment. Local Environment, 20(8), 957–980. https://doi.org/10.1080/13549839.2014.880411
- Thomas Beery. (2018). Engaging the Private Homeowner: Linking Climate Change and Green Stormwater Infrastructure. Sustainability, 10(12), 4791. https://doi.org/10.3390/su10124791

Module 9: Adaptive Management and GI

Learning Objective

- Discuss adaptive regulatory guidelines and GI implementation.

The design and performance of traditional infrastructure has been established based on centuries of precedent. Establishing the same level of certainty for green infrastructure systems will require decades of testing, but the need for implementation is pressing and immediate. Adaptive regulatory guidelines will allow municipalities to determine more detailed performance characteristics over time and incorporate new evidence into established best practices as it becomes available. This module will explore strategies for adaptive management of GI and its potential to reduce the time it takes for proven best practices to become engineering standards and to encourage innovation without sacrificing infrastructure quality or durability.

Municipalities traditionally meet their infrastructure servicing goals through static engineering design manuals which provide specific guidance related to every aspect of municipal design and are based on decades or centuries of precedent. However the impacts of climate change are upending these precedents and making existing infrastructure obsolete. Municipalities must now design infrastructure in an environment of increasing uncertainty, requiring more adaptable regulatory frameworks. Adaptable regulatory frameworks represent a significant deviation from traditional infrastructure standards but may be well-suited to opportunistically implementing GI on public and private lands to supplement traditional infrastructure systems as needed. The uncertainty associated with green infrastructure requires municipalities to more efficiently adopt and reject designs, principles, and technologies while minimizing the risk exposure inherent to experimental public service provision. In addition to promoting climate change resilience, adaptive regulatory guidelines are essential for ensuring that GI designs are continuously updated to align with the evolving best practice of GI implementation. The Sustainable Technologies Evaluation Program (STEP) Low Impact Development Stormwater Management Planning and Design Guide wiki is an excellent example of a tool that can be used to rapidly disseminate GI best practices and design guidance.

The living components of green infrastructure require a living document to regulate them. There is inherent variability in the functioning of living infrastructure and an overwhelming variety of living components to incorporate. The complexity of evaluating all the goals associated with GI is one of the greatest hurdles to its implementation. It is important that municipalities pursue training and capacity development along with design tools and guidance for internal engineering staff and private developers.

Adaptive regulatory guidelines will allow municipalities to determine these characteristics over time and incorporate new evidence and performance metrics into their established best practices. Adaptive GI allows a City to meet its performance goals while minimizing the risks of under-performing infrastructure systems and future re-development costs. Success of the adaptive management strategy is dependent on the municipalities ability to adopt and implement new guidelines in response to emerging evidence and best practices.

Learning Activities

Discussion Questions

- What are the enabling policies and programs that support successful GI implementation? Based on your readings so far, what city is a model for working with such approaches?

Readings & Resources

Readings

- Dong, X., Guo, H., & Zeng, S. (2017). Enhancing future resilience in urban drainage system: Green versus grey infrastructure. Water Research, 124,

280–289

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- Blue and Green Cities
  - The Role of Blue-Green Infrastructure in Managing Urban Water Resources
  - Adaptive Management and Blue-Green Infrastructure – pg. 43 – pg. 63
- Integrating Green and Gray (World Bank, 2018)
  - Why Integrate Green and Gray Infrastructure
- Enabling Policies for Effective Green Infrastructure pg. 73-81
- Handbook on Green Infrastructure Planning, Design, and Implementation
  - Chapter 4- Putting an Economic Value on Green Infrastructure
- EU Green Surge Guide (Hansen, 2017).pdf

Additional Resources and Citations

- Truffer, B., Störmer, E., Maurer, M., & Ruef, A. (2010). Local strategic planning processes and sustainability transitions in infrastructure sectors. Environmental Policy and Governance, 20(4), 258–269. https://doi.org/10.1002/eet.550
- Johnson, P. A., Tereska, R. L., & Brown, E. R. (2002). Using technical adaptive management to

improve design guidelines for urban instream structures1. JAWRA Journal of the American Water Resources Association, 38(4), 1143–1152. https://doi.org/10.1111/j.1752-1688.2002.tb05552.x

- Sussams, L. W., Sheate, W. R., & Eales, R. P. (2015). Green infrastructure as a climate change adaptation policy intervention: Muddying the waters or clearing a path to a more secure future? Journal of Environmental Management, 147, 184–193. https://doi.org/10.1016/j.jenvman.2014.09.003
- Berry, J., & Danielson, L. (2015). Paying for Urban Infrastructure Adaptation in Canada: An Analysis of Existing and Potential Economic Instruments for Local Governments. Simon Fraser University.

Module 10: Innovations in GI

Learning Objective

- Examine best practices and technologies that are pushing the boundaries of GI performance and planning.

The UN estimates that nearly 70% of the global population will live in cities by 2050, yet uncertainty remains as to how the current infrastructure can accommodate this rapid increase in population and associated infrastructure needs; a significant leverage point for integrating GI to augment and/or replace conventional infrastructure (Ritchie, 2018). The difficulties of accommodating this demographic shift are compounded by the impacts of climate change and potential corresponding loss of existing natural areas. Addressing the uncertainties and potential impediments to GI design and employment is essential to mitigating the environmental damage from 20th century urbanization and minimize the potential for continued ecological impacts into the future. Recent advances in GI science and technology hint at the possibilities of how GI can help facilitate urbanization and mitigate environmental harm to enable and support increased resilience to change.

One of the most important categories of GI innovations are efforts to more accurately account for the benefits that GI systems provide. Municipalities, national agencies, and academic institutions are developing easy-to-use calculators that can provide broad estimates of GI benefits; such as heat island reductions, ecological improvements, livability benefits, and water quality improvements. These innovations allow municipalities to make better informed decisions regarding GI design and investment and can support informed decision making in terms of quantifying the full range of benefits a GI system can provide. Stormwater management benefits of GI are continuing to be refined as innovative designs are tested for new performance variables, such as microplastic removal and microbiota concentrations. New materials or new uses of old materials are continuing to 'push the envelope' of GI performance standards.

An important innovation in GI employment is expanding municipal understanding of GI from single, isolated systems, to expansive networks that can address larger, city-wide demands and requirements. GI systems are being integrated into city planning efforts to optimize the benefits that GI can provide. GIS analysis is enabling greater information and understanding as to where GI can be effective and what information should be considered in implementation decisions. In Ottawa, a machine learning algorithm is compiling municipal GIS data to enable city engineers to choose the most proficient and effective sites for GI applications. Heat-mapping and socio-economic data is being used in the City of Vancouver to ensure that GI is implemented with a lens towards equity and city livability. Blue-green corridors are being used throughout Ontario to protect against floods and provide recreation space for residents.

Active monitoring of grey and green infrastructure system performance is also expanding what cities can achieve through green infrastructure. To date, GI systems have largely relied upon passive methods to reduce peak flow; the infiltration rate of soil, the number of orifices in a perforated pipe, the size of an overflow inlet. New methods of experimental control and system modelling are allowing cities to predict and optimize GI performance with greater precision and accuracy. Active sewer system monitoring and remote GI system control will allow city engineers to hold back and release water from GI systems as needed to accommodate back-to-back storm events or retain water in times of drought or potential sewer overflow. Active monitoring of groundwater levels may allow city planners make informed decisions on where GI can most effectively contribute to replenishing groundwater and improving urban water security.

Planning for biodiversity using GI requires supporting and protecting existing ecosystems and important biodiversity principles include habitat protection, connectivity and multitropic interactions. GI can prioritize habitat protection by providing habitat or creating buffer zones for existing habitat. Three case studies are presented in this module that highlight policy and GI tools fit for scale.

Learning Activities

- As you review the reading and video cases, consider which of the GI systems described is most interesting to you? Which do you think would be most applicable in your municipality?

Discussion Question

- Which of the innovative GI systems described in the readings and videos is most interesting to you and why?

Readings & Resources

Readings

- Xiang, C., Liu, J., Shao, W., Mei, C., & Zhou, J. (2019). Sponge city construction in China: Policy and implementation experiences. Water Policy, 21(1), 19–https://youtu.be/rrY1ohMLXiM37. https://doi.org/10.2166/wp.2018.02

Videos

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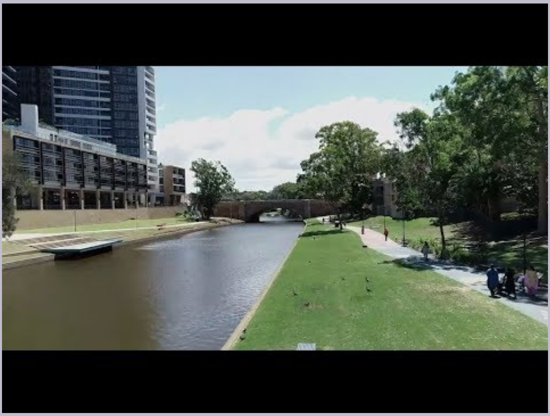

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Additional Resources and Citations

- EPA Stormwater Calculator

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- Integrating Green and Gray (World Bank, 2018) Why Integrate Green and Gray Infrastructure
    - The Economics of Green Infrastructure & Creating New Financing Options with Green Infrastructure pg. 51-73
- Wamsler, C. (2015). Mainstreaming ecosystem-based adaptation transformation toward sustainability in urban governance and planning.

Ecology and Society, 20(2). https://doi.org/10.5751/ES-07489-200230

- Mao, X., Jia, H., & Yu, S. (2017). Assessing the ecological benefits of aggregate LID-BMPs through modelling. Ecological Modelling, 353, 139–149. https://doi.org/10.1016/j.ecolmodel.2016.10.018
- The Economic Value of Natural Capital Assets Associated with Ecosystem ProtectionTown of Aurora(Kyle, 2013)
- Natural Values: Linking the Environment to the Economy(Ducks Unlimited Canada, 2020)

Module 11: Regional Planning for Resilient Communities

Learning Objectives

- Gain an understanding of the significance of regional planning for GI.

Cities that integrate GI into urban planning on many levels may reap the greatest benefits from GI systems. Creating more resilient cities requires an approach to GI that transcends the application of individual systems and focuses on how large-scale green spaces can be integrated into a city's infrastructure and its goals for regional planning; from citizen engagement to district planning and development applications. Planning for green infrastructure on a regional level allows for green infrastructure systems that offer significantly more services than a roadside bioretention system. With effective city planning, storm sewers and cisterns can be replaced with riparian corridors and floodable landscapes, offering improved flood protection, better water quality, and expanded habitat alongside recreational pathways, trails, and parks. Large-scale GI represents a valuable public allocation of multi-purpose and easily re-purposable land.

Conventional stormwater infrastructure was designed to be out of sight and out of mind; occupying as little visual space as possible, while minimizing the potential for damage. GI on the other hand is largely visible and, unless otherwise posted, accessible to the public such as alongside a city street, urban waterways, urban green space, etc. GI provides the opportunity for neighbourhoods to work together to design, employ and maintain the GI while also encouraging community ownership of GI and thus often mitigating for the potential of vandalism. GI also provides a chance for cities in settler-colonial nations to learn from and support First Nations peoples, whose knowledge of plants and ecosystem maintenance has historically been disregarded. In Vancouver, Canada, the Cities Green Infrastructure Implementation division is working with local First Nations to identify goals for GI performance, design, and implementation.

Planning for GI requires assessments of the value of the natural assets being planned for. The most site-suitable and affordable GI systems are the ones that already exist: urban waterways, boundary forests and urban tree stands, community green spaces, parks and recreation areas, and unmodified coastline. Preserving these systems often requires a comparison of their true value (including water treatment, ecosystem services, public health, climate resilience, etc.) with the cost of providing these benefits with conventional infrastructure.

Regional planning provides the potential for the employment of GI at the 'watershed' level (keeping in mind that regional government jurisdictional boundaries do not always follow watershed boundaries) providing municipalities with the ability to coordinate with other regional governments to make larger, interconnected systems that acknowledge the reality that our political boundaries rarely match hydrologic or ecological ones. The Ontario Conservation Authorities, which are organized by watershed as opposed to regional districts, are an example of the importance of working within natural, as opposed to political, boundaries. Municipalities within the same watershed or habitat can achieve similar ends by creating dedicated working groups to coordinate and influence provincial legislation and regulations to enable and support GI planning to create wildlife and riparian corridors on geographically relevant scales and then strategically scale down to the community level. Regional planning for resilient communities can be amplified with support from federal and provincial governments. The multi-functionality of GI makes it likely that that some portion of its intended benefits is also a priority for a larger regional or federal governing body increasing interest in supporting communities and regional governments across Canada with the strategic employment of GI.

Learning Activities

Discussion Question

- What advantages can arise from regional planning efforts that cannot be achieved through municipal planning?

Readings & Resources

Readings

- Rain City Strategy – Watershed Characterization Efforts
- Lerer, S., Arnbjerg-Nielsen, K., & Mikkelsen, P. (2015). A Mapping of Tools for Informing Water Sensitive Urban Design Planning Decisions-Questions, Aspects and Context Sensitivity. Water, 7(3), 993–1012. https://doi.org/10.3390/w7030993
- Golden, H. E., & Hoghooghi, N. (2018). Green infrastructure and its catchment-scale effects: An emerging science. WIREs Water, 5(1), e1254. https://doi.org/10.1002/wat2.1254
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Videos

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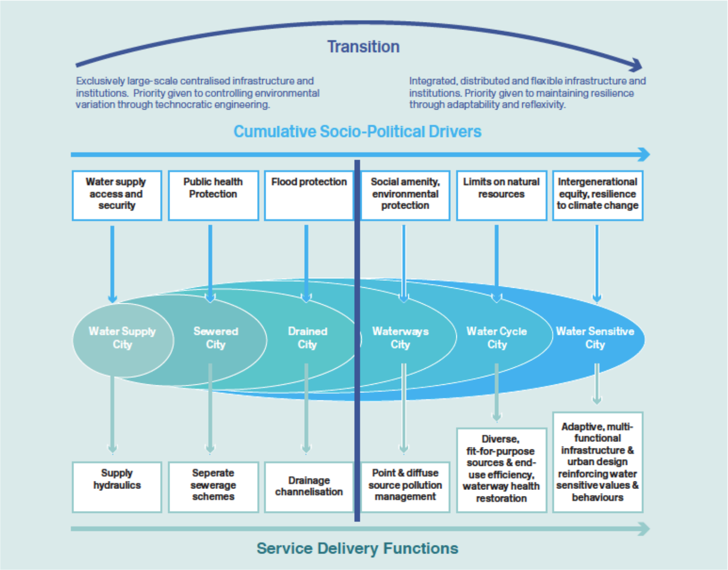
Additional Resources and Citations

- Planning the Pacific Northwest. Edited by Jill

Sterret, Connie Ozawa, Dennis Ryan, Ethan Seltzer, and Jan Whittington. American Planning Association/Planners Press.

Module 12: Leadership for GI

Congratulations! You have arrived at the end of your learning journey. Now is the time to take stock of your learning and to consider what kind of leadership you can bring to moving the GI conversation forward. We know from research that a focus on technical innovation will not be enough to realize a full integration of GI systems in how urban centres approach water management. It is also important to understand the social and institutional dynamics that underlie any city's attempt at integration. In the article 'Moving toward Water Sensitive Cities ' we revisit a framework for what a water sensitive city can look like, and what the motivations, drivers and arguments are for each phase in the transition.



Source: From page 12 of Moving Toward a Water Sensitive City, 2016.

For change to happen in small and big ways, shifts will be needed in several domains to bridge units and organizations: in the actors who participate (including professionals working in diverse sectors) and the public. We need interdisciplinary knowledge, innovative projects and the use of diverse policy and planning tools. (Toward a Water Sensitive City, p 16).

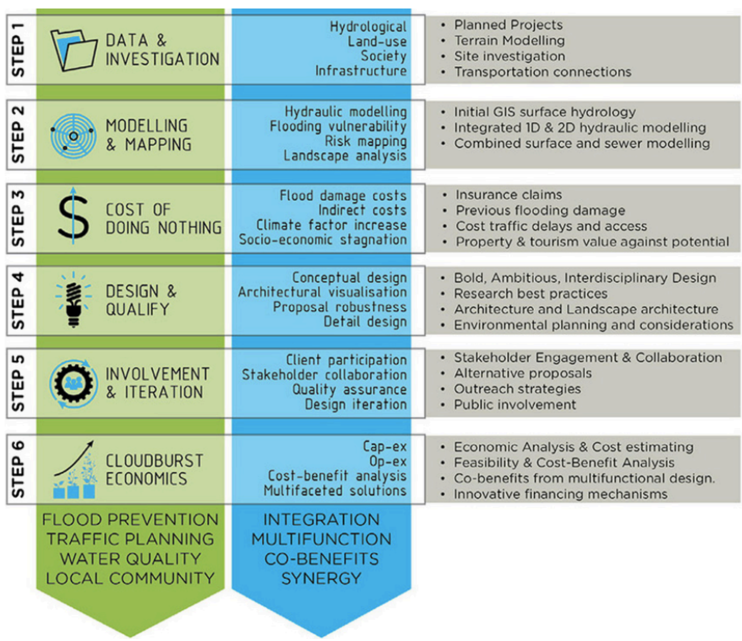
What is the leadership that is needed to make this happen? At its core GI leadership is interdisciplinary. All professional disciplines in both the public and private sector are required. Such leadership will require having a vision and a narrative that focuses on the quality of life that GI brings to an urban setting. In a recent report prepared by Danish researcher Helleshøj Sørensen, who studied the water resilience, water systems and urban qualities of Vancouver, Rotterdam and Copenhagen, she outlines the important role that compelling water narratives, the professions and an engaged community play in the blue-green transition.

Many of the writers and practitioners in the GI field note that designing and implementing experiments is one strategy for moving toward the Blue-Green vision. Experiments and programs by community organizations, universities, developers and municipalities build capacity and confidence in the design, planning and community engagement dimensions of GI.

Among the cases highlighted in Sørensen's study is the 'Cloud Burst Management Plan' of Copenhagen. It outlines a "state of the art" way of doing things in Copenhagen, which, she says, to be truly effective needs to be "a plan that is incorporated into the administration's general planning process, the municipal master plan, sectoral plans (e.g., wastewater plan), and local master plans, as well as in urban renewal plans and the local neighbourhood facelift scheme"

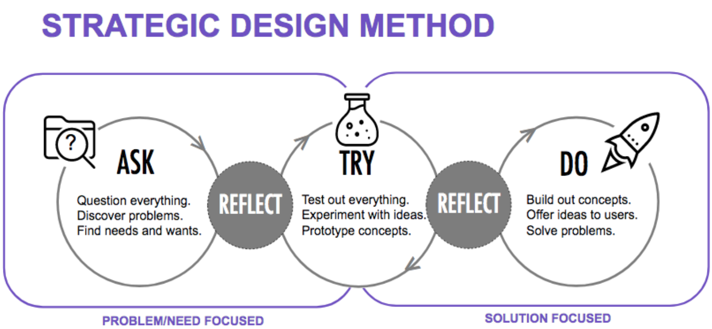
(City of Copenhagen, 2012). Clearly this approach requires a "joint effort and close coordination between the utility company, the municipality, the water industry, research institutions, and consultancies in developing new, practical, and successful solutions that only became possible due to alignment of understanding about water and the need for action" (Ziersen et al., 2017).

Copenhagen Cloudburst Formula: Blue-Green Solutions



Source: Helleshøj Sørensen (2019). From page 8 of https://acwi.gov/climate_wkg/minutes/Copenhagen_Cloudburst_Ramboll_April_20_2016%20(4).pdf.

The strategic design method is a useful tool for thinking about project design and has leaders asking important questions about problem definition and the design of solutions. This model by Quayle, is outlined in your reading. Specific tools for framing problems and solutions are also found in The Urban Green Infrastructure Planning Guide on pages 83-92.



Source: Qualye, 2017 From page 6 of http://blogs.ubc.ca/saladesigncharrette/files/2017/05/Quayle_StrategicDesign.pdf

Dealing with Obstacles

Communities across the country are experiencing the benefits of green infrastructure. They have adopted performance standards or incentives promoting green infrastructure while others have built demonstration projects. The article on barriers to adopting green infrastructure highlights typical obstacles confronted by municipalities, developers and designers and suggest strategies to overcome them.

Become Part of a Growing Learning Community: Adaptation Learning Network

There is a growing network of professionals who are committed to supporting climate change adaptation practices such as GI. The Adaptation Learning Network is committed to building a community of learners that exchange ideas across fields to better prepare for the effects of the climate crisis. If you have a story about climate adaptation from your GI experience and beyond that you want to share, please get in touch with them. They produce a podcast and original web content to amplify inspiring stories of climate action. You can find them at these links:

- LinkedIn
- Twitter
- Subscribe to our Newsletter

If you would like to provide feedback on your experience in this course to the ALN, please do so here in: this short survey.

A Learning Review

Now is the time in the course to take stock of **your** learning. Thinking back to the beginning of the course what were the learning goals you identified at that time? Where have you come? What are you taking away from the course experience via the readings, the interactions with other students and your course facilitator? What questions remain for you? We will take some time in the discussion forum to explore these questions and the final Zoom meeting will give you the chance to reflect together on the meaning of this learning for your practice. You will be invited to complete a short course evaluation to provide us with your feedback on your experience. We hope you will continue to stay connected with the growing network of professionals who are involved in GI for climate change adaptation.

Learning Activities

- Take a moment to review your learning goals from the beginning of the course.
- Review the readings for this unit and review the core resources available to you.
- Take part in the final discussion forum of the course reflecting on learning and questions remaining

Discussion Questions

- What has been the most significant learning for you in this course?
- What questions do you have about what has been covered in the course?

Readings

- Moving Toward a Water Sensitive City
- Vancouver's Water Narrative: Learning from Copenhagen and Rotterdam
- Quayle Presentation on Strategic Design
- Overcoming Barriers to Green Infrastructure
- Urban Green Infrastructure Planning
    - (Toolbox: pg. 83-92)
- Making Cities Livable – Ramboll (18 pages)

Additional Resources and Citations

City of Vancouver (Holistic Planning)

- Rain City Strategy

Greater Toronto Area (Conservation Authorities and Independent Watershed Management

- Green Streets Technical Guidelines
- LSRCA Phosphorus Management Program

The Netherlands (Research Through Design)

- Sustainable Cities in the Netherlands: Urban Green Spaces Management in Rotterdam
- Rotterdam Roofscapes

New York City (Standardized Streetside Bioretention)

- Right-of-way Green Infrastructure

A Vimeo element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=58

Minnesota (Documentation for Rainwater Management)

- Minnesota's Stormwater Manual

Chinese Sponge Cities (Urban laboratories and centralized planning)

- Xiang, C., Liu, J., Shao, W., Mei, C., & Zhou, J.

(2019). Sponge city construction in China: Policy and implementation experiences. Water Policy, 21(1), 19–37. https://doi.org/10.2166/wp.2018.021

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=58

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=58

Portland (GI and Health)

- Green Infrastructure & Health Guide

Seattle, Washington (GI for CSO reductions)

- Optimizing Green Infrastructure Techniques to Reduce CSO Volume in Seattle

Sydney, New South Wales, Australia – Green Grid (Networking Existing Green Spaces)

- Sydney Green Grid

Singapore (Large-Scale Rainwater Capture)

- What Singapore Can Teach All Cities About Using Urban Green Infrastructure To Mitigate Megadroughts

Stockholm (Greening Institutions)

- Stockholm – leading the way in sustainability

City of Vancouver (Holistic Planning)

- Rain City Strategy

Greater Toronto Area (Conservation Authorities and Independent Watershed Management

- Green Streets Technical Guidelines
- LSRCA Phosphorus Management Program

The Netherlands (Research Through Design)

- Sustainable Cities in the Netherlands: Urban Green Spaces Management in Rotterdam
- Rotterdam Roofscapes

New York City (Standardized Streetside Bioretention)

- Right-of-way Green Infrastructure
- Finding Room for Green Infrastructure in New York City – 10min

An interactive or media element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=6

Minnesota (Documentation for Rainwater Management)

- Minnesota's Stormwater Manual

Chinese Sponge Cities (Urban laboratories and centralized planning)

- Xiang, C., Liu, J., Shao, W., Mei, C., & Zhou, J. (2019). Sponge city construction in China: Policy and implementation experiences. Water Policy, 21(1), 19–37. https://doi.org/10.2166/wp.2018.021
- Sponge Cities – 2min

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=6

- Jiangsu Sponge City Flythrough – 3min

A YouTube element has been excluded from this version of the text. You can view it online here: https://pressbooks.bccampus.ca/greeninfrastructure/?p=6

Portland (GI and Health)

- https://willamettepartnership.org/wp-content/uploads/2018/07/Green-Infrastructure_final_7_12_18_sm.pdf

Seattle, Washington (GI for CSO reductions)

- https://www.researchgate.net/publication/272208901_Optimizing_Green_Infrastructure_Techniques_to_Reduce_CSO_Volume_in_Seattle

Sydney, New South Wales, Australia – Green Grid (Networking Existing Green Spaces)

- https://www.governmentarchitect.nsw.gov.au/projects/sydney-green-grid#:~:text=Known%20as%20the%20Sydney%20Green,quality%20of%20life%20and%20wellbeing.&text=Open%20space%20is%20one%20of%20Sydney's%20greatest%20assets.

Singapore (Large-Scale Rainwater Capture)

- https://www.smartcitiesdive.com/ex/sustainablecitiescollective/will-urban-green-infrastructure-help-mitigate-megadroughts/1047571/

Stockholm (Greening Institutions)

- https://professionals.visitstockholm.com/why-stockholm/artiklar-till-why-stockholm/sustainability/

Appendix B: Additional Citations and Resources

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