Shifting Shores and Perspectives:
Making Room for the Sea and the Storm in False Creek Flats

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Abstract

Coastal cities are grappling with how to shift their approach in designing the built environment to respond to global warming and sea level rise. With the potential increase of sea level rise by 1 metre by the year 2100, and climate change projecting more intense and frequent storms to British Columbia's coasts, Vancouver will need to consider more resilient approaches to address flood risk along its shores.

One area that will be exposed to flood risks includes the False Creek Flats, a historic tidal flat converted to rail and industrial hub in the core of the city, and on the cusp of transforming into the city's next employment hub. At present, it is indiscernible that the False Creek Flats at one time was a historic tidal flat with a rich ecology supporting a variety of plants and wildlife, providing food and sustenance to the Indigenous people whose traditional territory included this land. The emergence of the rail and industry erased this history, the connection to the water, and the dynamic coastal processes that shaped the landscape. With the False Creek Flats undergoing a significant transformation over the next number of years, there is a window of opportunity to reconnect False Creek Flats to the coastal landscape, while also making room for flood waters and shifting perspectives on how we live with and build with water.

This practicum seeks to develop a resilient design approach for False Creek Flats through three lenses: robustness, ensuring people are safe; adaptive, making room for the water; and transformative, shifting perspectives through design interventions. Leveraging the opportunity to make False Creek Flats resilient to climate change and flooding will benefit Vancouver by creating opportunities to shift public perspectives on how the city should adapt to sea level rise and climate change, while also bolstering public policy that will make the city and its residents more adaptive and resilient to change.

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Figure 0.1-1
False Creek Flats Context Map

Introduction

Coastal landscapes are dynamic and always in flux in response to sea level change, the ebb and flow of the tides, geomorphology, and the weather and climate of the region. Cities, however, tend to be built as relatively static systems with the intent to avoid or minimize change. Global warming is challenging this city building approach, and coastal cities are starting to take action due to the implications associated with sea level rise.

The Intergovernmental Panel on Climate Change estimates that global temperatures have increased 1.0°C above pre-industrial levels from anthropogenic activities, and are on track to reach 1.5°C as early as 2030 (IPCC, 2018, p. 6). Further, it is expected that the human-generated emissions in the atmosphere will persist for many years and will have long-lasting effects (IPCC, 2018, p. 7). This means that even with all the action that is being taken to minimize our impact on the environment, the earth will continue to warm and sea levels will continue to rise.

Sea level rise is particularly concerning to coastal cities, as salt water can damage infrastructure and destroy agricultural land, and flooding can immobilize cities by hampering transportation routes, cause water damage to buildings, and put people at risk when they are unable to escape or come in contact with contaminated water. As sea level continues to rise, society will need to shift its expectations for coastal landscapes and understand that the status quo comes at a social, environmental, and economic cost. Adapting to climate change will involve difficult and controversial decisions; however, continuing to maintain the status quo is not sufficient to address climate change, nor is it sustainable. Acknowledging this, the City of Vancouver has begun to study the impacts of sea level rise and consider possible solutions to manage the risks. Included in the study is the False Creek Flats, a historic tidal flat converted to rail and industrial development, and now on the verge of transforming into the city's next employment hub. With climate change, False Creek Flats is at risk of flooding due to sea level rise and stormwater back-up from a drainage system approaching its capacity. With False Creek Flats undergoing a significant transformation over the next number of years, there is a window of opportunity to make room for flood waters and shift perspectives on how we live with and build with water.

False Creek Flats is an interesting site to explore the intersection of design, landscape architecture, and climate change. When one visits False Creek Flats today, it is imperceivable that the site was once a historic tidal flat. All the memories of its ecological history and relationship to the larger coastal systems have been scrubbed and filled in to pave the way for rail and industrial development, in the name of progress and urban growth. Having created a disconnect with the coastal landscape has in part led to the predicament that False Creek Flats faces today in balancing goals that appear to be at odds with each other. City goals with achieving climate resiliency and regional policy expectations to that the False Creek Flats will drive economic growth as an employment hub.

Figure 0.1-2 Pacific Central Station


Figure 0.1-3 Terminal Avenue

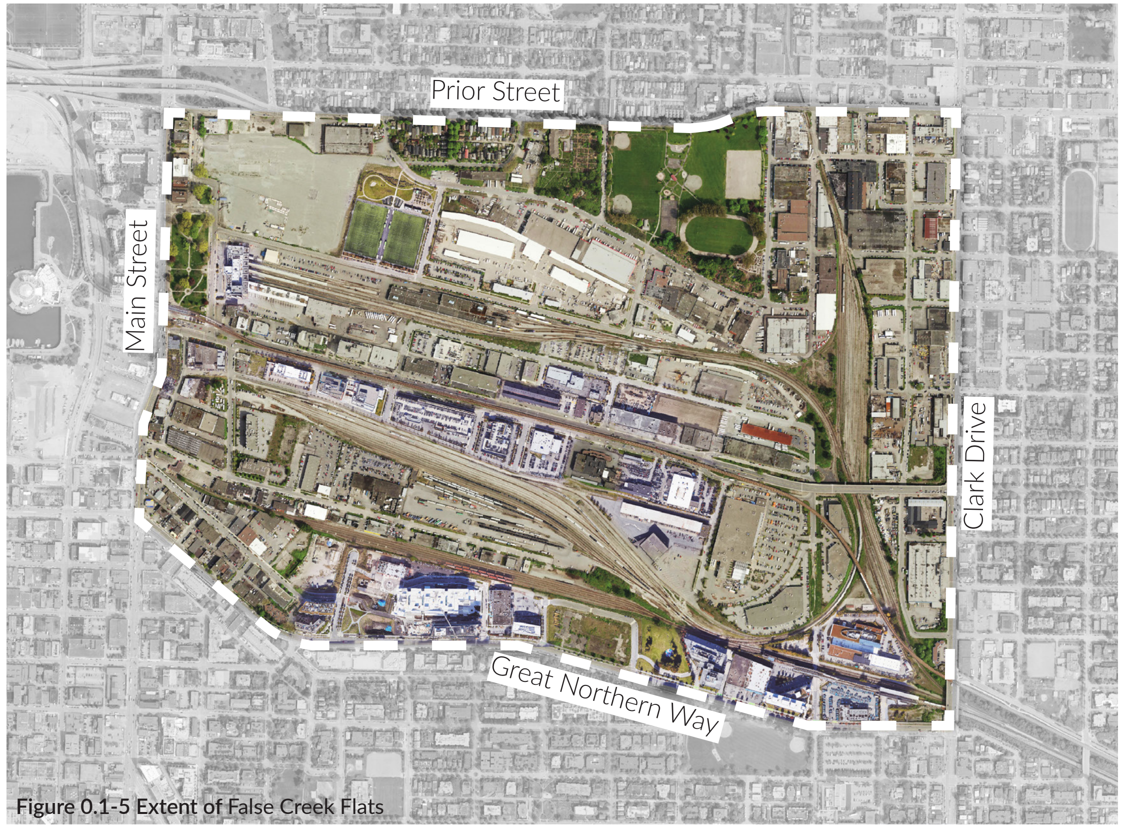

Figure 0.1-5 Extent of False Creek Flats


Figure 0.1-4 Trillium Park

Figure 0.1-6 CN Rail behind Terminal Avenue

As a student studying landscape architecture with an inherent bias towards finding ways to work with the landscape to find solutions to the environmental issues that our society faces, it is difficult to see plans for urban renewal that do not provide a clear road map on how the redevelopment of the False Creek Flats will address climate change. The False Creek Flats redevelopment plan acknowledges climate change and sea level rise; however, the plan does not illustrate how the area will respond to flood risks from sea level rise and stormwater in a meaningful way. The plan does not address the scale and magnitude of the issues this area will face as sea levels continue to rise and climate change brings more intense and frequent storms, increasing the pressure on the city's aging infrastructure and exposing people to health and safety risks, and businesses to potential financial losses. As such, this practicum seeks to develop a landscape infrastructural approach to make False Creek Flats resilient to flooding to minimize these risks.

This practicum will view resilience through three lenses: robustness, ensuring people are safe; adaptive, making room for the water; and transformative, shifting perspectives through design interventions. As part of this work, the practicum explores the cultural and geological context of the site; identifies factors that contribute to flooding in Vancouver; illustrates the flood risks the False Creek Flats faces, and reviews strategies to manage sea level rise and stormwater. Collectively, this research will inform a design strategy to make False Creek Flats more resilient to flooding, by making room for the water and providing opportunities for people to connect to the landscape to enhance their understanding of the coastal processes and to shift perspectives on how we live and build with water.

In considering the history of a site and through an understanding of coastal landscape processes, landscape architecture can provide land-based strategies to manage water to reduce flooding in the False Creek Flats. However, to generate resiliency, society needs to be able to adapt to and accept change. Adaptive design makes room for changing conditions and allows new opportunities to emerge. For society to accept significant change to the built environment, their property or even places they are attached to, they need to have an understanding of the forces causing climate change and the implications of inaction. Creating opportunities to engage with the processes and integrating beauty and design within the landscape can build this capacity. It can also make our built environments more successful, as people tend to take care of the places they value and appreciate. Design also provokes thoughts, passively educates, and informs perceptions. Public perceptions also tend to inform policy decisions, which ultimately leads to any action taken to tackle climate change. Leveraging the opportunity to make False Creek Flats resilient to climate change and flooding will also benefit the City of Vancouver by creating opportunities to shift public perspectives on how the city should adapt to sea level rise and climate change. Doing so can help support policy decisions that will make the city and its residents more adaptive to and resilient to change.

Chapter 1
An Introduction to False Creek Flats

1.1 History of False Creek Flats

- Historic Tidal Flat
- Development of False Creek and Surrounding Areas
- Strathcona Neighbourhood
- Main Street (Westminster Avenue)
- British Columbia and the Electric Railway
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- Economy and Land Use
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Figure 1.0-1 (Left)
Shoreline area of False Creek flats (sic)

Section 1.1 History of False Creek Flats

Figure 1.1-1
Historic shoreline and lost streams of Vancouver

Historic Tidal Flat

Before being reclaimed, the False Creek Flats was part of False Creek, a small inlet, where water saturated the area during high tide. Consisting of brackish waters, the confluence of saltwater and freshwater, the Flats was fed by a number of streams and creeks that provided a productive environment for a variety of fish, shellfish, and plants. False Creek provided a rich ecological zone in juxtaposition to the densely wooded fir, cedar, and hemlock forest that covered the slopes surrounding False Creek, along with the rest of Vancouver (Donald Luxton and Associates Inc., 2013, p. 7).

The exposure to the sky allowed plants to grow in contrast to the forest, where very little sunlight reached the forest floor. The fish and plants of False Creek provided food not only for animals but also a food and medicine source for the Coast Salish peoples (Ibid., p. 8). The fresh water supply, flora, and fauna proved to be fruitful for sustenance due to the overlapping territories of the Musqueam, Squamish, and Tsleil'waututh Indigenous groups (Ibid., p. 8). Indigenous camps also were present in the Grove Crescent area, north of the False Creek eastern reaches (Ibid., p. 7). On what would have been a peninsular projection, this area provided a safe place to camp while also providing sight lines to the surrounding area and easy access to the food and water sources nearby (Ibid., p. 7).

Towards the west, False Creek extends to English Bay, which at one time was lush with densely grown forests of fir, cedar, and hemlock (Ibid., p. 7). Its deeper waters provided easier navigation compared to the eastern side of False Creek, present-day False Creek Flats, which was stagnant due to where the peninsulas constricted the water by present-day Main Street (Ibid., p. 7). The restriction of water movement, however, allowed for the "growth of grasses, willow, and crabapple trees" and habitats for "a variety of shellfish, including clam and crab" (Ibid., p. 7). The marshy area also provided "ideal conditions for the rearing of young salmonids" (Ibid., p. 7).

A network of streams poured fresh water into False Creek. Two of the largest creeks included Brewery Creek and China Creek to the south. Brewery Creek, which includes a ravine up to 12 metres deep, was a vital tuna and salmon run in the Vancouver area (Ibid., p. 8). China Creek, also referred to as Jones Creek, connected over 16 kilometres of creeks, generating momentum for a fast flowing stream that carved a steep canyon close to what is currently East Broadway (Ibid., p. 8). The network streams provided a way to navigate and traverse the terrain, reaching False Creek, and heading west towards the Burrard Inlet and further out to the Pacific Ocean (Ibid., p. 8).

Along Brewery Creek one might find deer fern, licorice fern, spirea, devils club, skunk cabbage, and stinging nettle; and, in the spring, yellow violets, twinflowers, mayflowers, and pigeonberry flowers would bloom (Ibid., p. 8). The summer would provide a host of berries, such as blueberries, blackberries, red huckleberries, salal berries, thimble berries, black caps, and red and yellow salmon berries (Ibid., p. 8). Some of the wildlife in the area included deer, elk, cougars, bears, beavers, and a variety of birds and insects (Ibid., p. 8). False Creek Flats, also known as 'Skwahchays' by the Squamish people, attracted mallards, teal, butterball, and pintail ducks, as well as other birds of the Pacific Flyway (Ibid., p. 8). Birds such as grouse, partridges, swans, and ducks also congregated where the freshwater met the flats (Ibid., p. 8). A sandbar on the west side of False Creek, in the location of present-day Granville Island, supported the hunting and trapping of fish, such as salmon, trout, flounder, perch, sole, and smelt (Ibid., p. 7). Fish traps were developed by fixing fences and twisting brush into the sand and using cedar and spruce to make ropes and stinging nettle to provide fiber for fine netting (Ibid., p. 7).

The populations of the Musqueam, Squamish, and Tsleil'waututh peoples declined substantially after the Europeans arrived to explore and colonize their lands (Ibid., p. 8). In 1859, Captain George Richards, along with the Royal Navy, surveyed the northwest coastlines (Ibid., p. 8). European settlement followed in 1867, and by 1870, there were only forty-four indigenous people recorded as living in the False Creek area (Ibid., p. 8).

Figure 1.1-2 (Right)
Shoreline area of False Creek flats (sic) (2)

Development of False Creek and Surrounding Areas

Sawmills were the earliest forms of industry within the area, as the lumber from the old growth forests proved to be a valuable international resource. One of the first sawmills included Captain Edward Stamp's sawmill along the south shore of the Burrard Inlet, which later became the Hastings Saw Mill (Donald Luxton and Associates Inc., 2013, p. 10). The Hastings mill was so successful that by 1870 it owned approximately 40 percent of the area of present-day Vancouver in timber leases (Ibid., p. 10). By 1875, the eastern slopes of False Creek were being logged by Jeremiah Rogers, who operated a camp at Greer's Beach, present-day Kitsilano Beach, and the lumber processed in British Columbia was considered such high quality, it had buyers as far as Australia and China (Ibid., p. 10). The success of the timber industry also helped ensure the transportation network to New Westminster and Moodyville, and the development of the bridge over False Creek at present-day Main Street, previously known as Westminster Avenue (Ibid., p. 10).

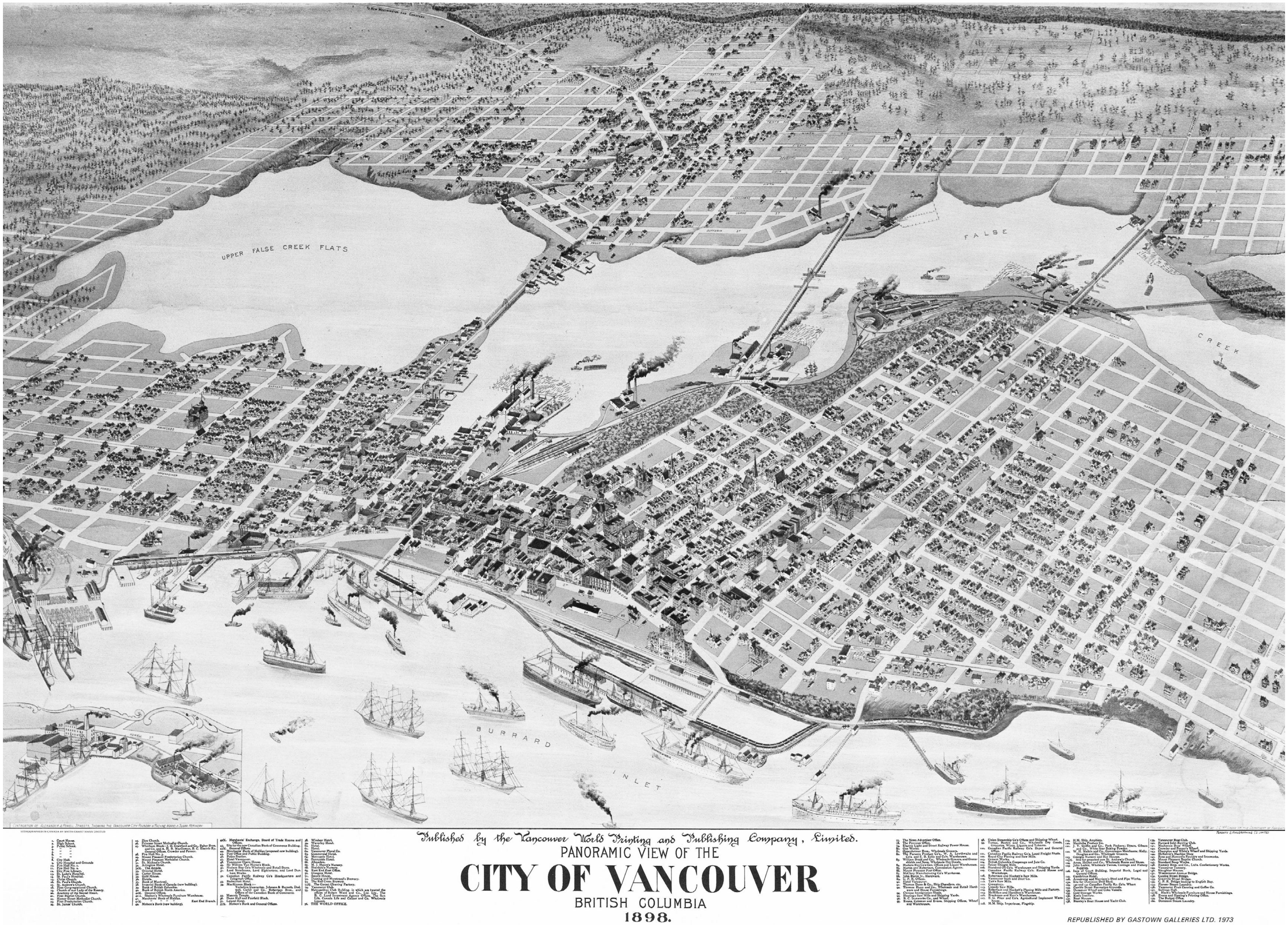
The timber industry helped encourage trade routes to the Lower Mainland, including the development of a bridge that crossed False Creek at the present location of Main Street, which was a significant development as it connected the sawmills on the north side of False Creek and along the Burrard Inlet with the Granville settlement (Ibid., p. 10). Later a road extended from the bridge, North Arm Road, connecting to the farms on Lulu and Sea Islands, presently part of the City of Richmond, situated on the Fraser River Delta (Ibid., p. 10). These farms helped supply food and provisions to both the settlement of Granville and the sawmills. George Black's slaughterhouse, one of the first industrial plants in the area, was also enabled by the development of the North Arm Road, and located on the north side of the bridge at False Creek in 1879 (Ibid., p. 10). At the time, this area was still very much considered remote, and it was not until the emergence of rail that "Vancouver's position as a remote industrial backwater changed" (Ibid., p. 10).

In 1881, a surveyor with the Canadian Pacific Railway (CPR) came to survey the area for their western terminus (Ibid., p. 10). Initially it was thought that Port Moody would be the site for the terminus; however, the water was too shallow to be used as a port, and the area was too confined. Although the CPR had decided that Port Moody would be an unsuitable site, they held off announcing their decision to leverage a better deal to move their terminal further west (Ibid., p. 10). As they predicted, the Province enticed the CPR to set the terminal at the Granville settlement, in exchange for 6000 acres of land (Ibid., p. 10). Further to their advantage, "private land-owners along the waterfront donated one-third interest in their property to ensure that the CPR would build railway docks on Burrard Inlet" (Ibid., p. 10).

False Creek was a desirable location for the terminal, being close to English Bay and the Georgia Strait. Being a primary landowner of the area allowed the CPR to decide what businesses should be located where to the advantage of the CPR (Ibid., p. 10). With so much influence over the area, the president of the CPR, Sir William Van Horne strategically suggested the settlement be named 'Vancouver,' implying that the area was closer to Vancouver Island (Ibid., p. 10). With development expanding in Vancouver, most of the waterfront along False Creek became developed with the shores spotted with sawmills, and other industries that produced and materials such as brick, lime, cement, gravel, and sand (Ibid., p. 11). False Creek provided a convenient area for log blooms, and unfortunately, an area to dump waste (Ibid., p. 11).

As development continued to progress, City Council looked to find ways to take control of the city and sought numerous times to gain the foreshore rights of False Creek from the federal government (Ibid., p. 11). After the great fire in 1886, which destroyed most of Vancouver's building stock, City Council sponsored the construction of the Granville Street bridge that would connect Vancouver and the Fraser River to the downtown (Ibid., p. 11). The west side of False Creek was much more active with its deeper waters and connection to English Bay; however, the shallow waters at False Creek Flats were much more stagnant and not suitable for navigation (Ibid., p. 12). Becoming an eyesore accumulating debris and waste, the CPR suggested that the east end (the False Creek Flats) should be filled and by 1912, the City's shores, including False Creek, were surveyed (Ibid., p. 12).

Figure 1.1-3
View of Leamy and Kyle Sawmill on False Creek


UPPER FALSE CREEK FLATS
FALSE
CREEK
BURRARD
INLET
Published by the Vancouver World Printing and Publishing Company, Limited.
PANORAMIC VIEW OF THE
CITY OF VANCOUVER
BRITISH COLUMBIA
1898.
REPUBLISHED BY GASTOWN GALLERIES LTD. 1973

Strathcona Neighbourhood

To the north of False Creek is the Strathcona neighbourhood, one of Vancouver's oldest neighbourhoods and often referred to as the 'East End' (Donald Luxton and Associates Inc., 2013, p. 16). Its development was facilitated by the Hastings Mill that originated in the area; however, after the great fire in 1886, Strathcona developed into a vibrant mixed-use neighbourhood (Ibid., p. 16).

On the north side of False Creek Flats is the residential niche of Grove Crescent. This area was once home to Indigenous camps and a peninsula that projected inwards towards the flats when water was still present (Ibid., p. 16). In the late 1800s, the residential enclave was home to many immigrant families working in the surrounding area and for the British Columbia Electric Railway (BCER) (Ibid., p. 17). Chinese workers from San Francisco also made this area and the Strathcona neighbourhood their home, while also establishing Chinatown to the west at Carrall and Pender Street (Ibid., p. 16). Chinese workers that were less fortunate lived in shacks occupying the mud flats of False Creek, many of which were built on stilts to accommodate the tidal nature of the flats (Ibid., p. 16).

In 1909, the Great Northern Railway (GNR) received permission to fill in part of the False Creek Flats area, by 1912 they purchased and removed the homes in Grove Crescent, and the majority of the False Creek Flats was filled in by 1918 (Ibid., p. 16). Despite the industrial development, Grove Crescent maintained an agricultural heritage, as research notes that residents kept their cows in backyard barns (Ibid., p. 17).

After years of non-investment in the neighbourhood, Strathcona deteriorated significantly after the Second World War. By the 1950s, Strathcona was considered a slum and a visual blight to the city (Ibid., p. 17). The City Council of Vancouver proposed to redevelop the area entirely, demolishing many city blocks to pave the way for new modern-style residential developments, much of which done without any consultation to the residents of Strathcona. In the final phase of redevelopment, the City planned to construct a freeway that would have dissected Strathcona, providing another crossing into the north shore of False Creek (Ibid., p. 17). However, the redevelopment scheme met strong opposition by the Strathcona Property Owners and Tenants Association and eventually a community-driven plan was developed to upgrade the existing infrastructure and amenities in the area (Ibid., p. 17). Although this halted the project for the freeway, the Georgia and Dunsmuir Viaducts had already been constructed (Ibid., p. 17).

Figure 1.1-4 (Left)
Panoramic view of the City of Vancouver, British Columbia, 1898

Main Street (Westminster Avenue)

Main Street, initially Westminster Avenue, provided a direct link to New Westminster (Donald Luxton and Associates Inc., 2013, p. 20). In 1872, the first bridge would be built to cross False Creek along Main Street; however, it had to be rebuilt just four years later due to the deterioration of the pilings from teredo worms (Ibid., p. 20). Main Street served as a primary corridor and encouraged a range of commercial and industrial development along its edges, including the slaughterhouse at the north end of the bridge, and the Guerney Cap and City Market at the south (Ibid., p. 20). Although not as successful as hoped, the architecture of City Market had a Victorian train station grandeur to its design, and the building lasted until the 1920s when it succumbed to a fire (Ibid., p. 20). Its strategic location suggests the importance of Main Street as a major transportation corridor that linked Vancouver to the surrounding areas (Ibid., p. 20).

Bridge Hotel was one of the first hotels constructed to service the False Creek area and was built in 1885 near the foot of the original Main Street bridge (Ibid., p. 23). In the early 1900s, three additional hotels were built, including Ivanhoe (formerly Hotel Cunningham), Cobalt (formerly the Royal George Hotel), and the BCER Men's Quarters, located between Prior Street and National Street (Ibid., p. 23). These hotels were constructed to house the workers of the surrounding transportation and industrial businesses, and formed a distinct edge along what would have been waterfront properties along Main Street (Ibid., p. 23).

Figure 1.1-5 (Right)
Vancouver B.C. from the South

British Columbia and the Electric Railway

Before becoming the British Columbia Electric Railway (BCER), the Vancouver Street Railway Company successfully provided transit throughout the Vancouver area after its merger with the Vancouver Electric Illuminating Company (Donald Luxton and Associates Inc., 2013, p. 21). The original plan included horse-drawn vehicles, evident by the construction of a horse barn at the intersection of present-day Main Street and Terminal Avenue (Ibid., p. 21). However, the development of the young city called for a more forward-thinking transit system (Ibid., p. 21). The network first included travel from the horse barn north on Westminster Avenue (Main Street), "then ... Powell, Carrall, Cordova, Cambie, Hastings and Granville to Drake" (Ibid., p. 21). Expansion immediately after included a route that extended "up Granville, across Broadway through the Fairview district, and back down Westminster Avenue" (Ibid., p. 21).

With the growth of Vancouver, New Westminster planned to find a way to strengthen its connection to Vancouver, helping facilitate the emergence of the Westminster and Vancouver Tramway Company (Ibid., p. 21). This new interurban line helped passengers and freight travel more conveniently between Vancouver and New Westminster, while also spearheading development along Kingsway, a primary corridor connecting the two cities (Ibid., p. 21). The tramway was considered North America's "first true interurban railway" (Ibid., p. 21).

After the Vancouver Street Railway Company went through financial troubles, the company switched ownership and became the British Columbia Electric Railway (Ibid., p. 21). Under new ownership, rail routes expanded at a faster rate, pushing development into Vancouver's hinterland (Ibid., p. 21). The line between New Westminster and Vancouver expanded to a double track and became known as the 'Central Park Line,' although trolley buses eventually replaced the trains and streetcars, the corridor influenced the development of the False Creek Flats (Ibid., p. 22).

Figure 1.1-6 (Above)
Central Park Line in the Early Days

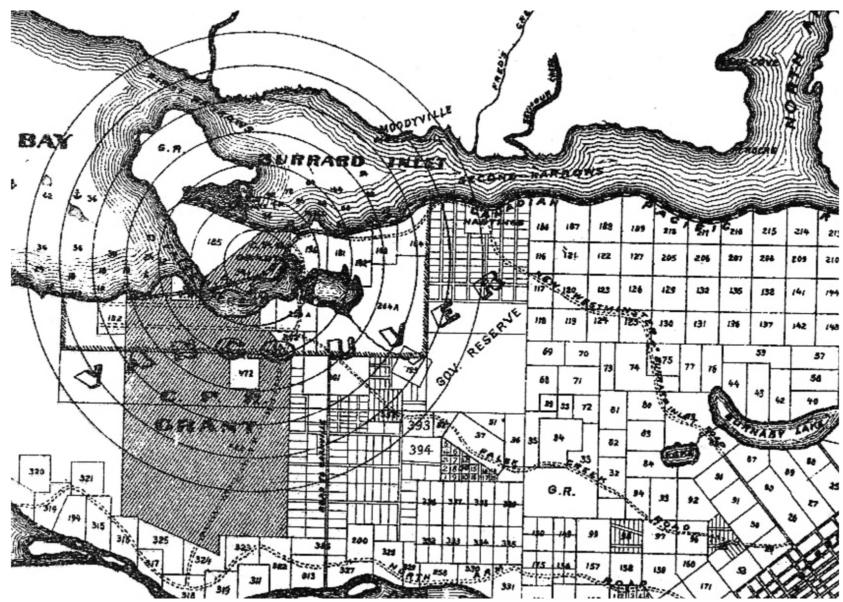
Figure 1.1-7 (Right)
Plan of the City of Vancouver. Western Terminus of the Canadian Pacific Railway

Rail and the Landscape

The emergence of the CPR rail line transformed the False Creek landscape, dominating the ownership and development of Vancouver.

Interest in Vancouver grew substantially during the gold rush in the Yukon during the 1890s with Vancouver becoming one of Canada's primary seaports in the early 1900s (Donald Luxton and Associates Inc., 2013, p. 26). This growth attracted many immigrant families to the Vancouver area (Ibid., p. 26). The CPR established itself primarily on the Burrard Inlet, but with their land holdings, the CPR also developed nearby subdivisions, including the affluent neighbourhood of Shaughnessy Heights, located south of False Creek (Ibid., p. 26). Most of the residents of this area came from either the West End or from the Fairview slopes where they were escaping strong sewer odours (Ibid., p. 26). The CPR also had a strong influence on the development of the downtown, constructing their passenger station on the waterfront of the Burrard Inlet, the "original Hotel Vancouver, the city's first opera house," and many other buildings and amenities in the downtown core (Ibid., p. 26). The CPR even laid out the street grid in the city's core and named the streets "after railway officials such as Abbott, Cambie, Hamilton, and Beatty" (Ibid., p. 26).

Between 1904 to 1907, the population grew from 38,000 to more than 65,000, making Vancouver the largest city in British Columbia (Ibid., p. 27). As Vancouver became more populated and developed, dissent among the residents grew against the CPR's monopoly over the city. With the support of the residents and the province, the City was encouraged to find a way to lift the control CPR had over the land and encouraged rail competition to the area (Ibid., p. 27). This competition began with the arrival of the Vancouver, Westminster, and Yukon Railway (V, W, & Y) in 1904 (Ibid., p. 27). This new rail line entered the city north of "BCER's New Westminster interurban line, crossed False Creek on the Westminster … trestle, and terminated in Chinatown" (Ibid., p. 27). In 1903, the Great Northern Railway (GNR) arrived, and by 1909 the Canadian Northern Railway (CNoR) built its line to the west coast (Ibid., p. 27). It was during this time that GNR proposed filling in the flats to make way for their rail yards, as a means to circumvent the CPR's monopoly (Ibid., p. 27).



Filling of the Flats

The False Creek flats were not filled all at once, but during phases as industrial and rail activities expanded in the area. The most substantial fill, between Main Street and Clark Drive, took place after the 1912 waterfront survey (Donald Luxton and Associates Inc., 2013, p. 30). With the intent to escape CPRs control, the City entered talks with GNR and CNoR about developing the tidal flats, for the use of their rail yards and terminals (Ibid., p. 30). The city proposed the idea to the public through a referendum held on March 15, 1913, which resulted in a majority in favour to fill the flats, although this was to the dismay of opponents with investments in the Port Mann area (previously Bon Accord) another area that was subject to speculative terminal developments (Ibid., p. 32).

Work on reclaiming the flats commenced in 1915, the same year the Georgia Viaduct was constructed, a "single-bridge structure traveling along the Georgia Street axis from Main Street to the escarpment near Beatty Street" (Ibid., p. 32). The composition of the fill that went into the flats included material excavated from other parts of the city that were under development, "scrap lumber and bricks from the surrounding mills," and other general waste from the surrounding industrial activities (Ibid., p. 32). Both the GNR and CNoR terminals required pilings because of the nature of the filled land and surrounding construction; both terminals were constructed by 1919 (Ibid., pp. 32-33).

The new terminals brought raw materials into and out of Vancouver, and the yards consisted of a number of large rail sheds. Within proximity to the core, the land was initially considered too valuable to be only used for industrial developments; however, the synergy of being close to rail transport encouraged the development of industrial facilities and warehouses throughout the Flats (Ibid., p. 33).

Strathcona Park

A small section of the northern side of the flats remained as water near present-day Strathcona Park (Donald Luxton and Associates Inc., 2013, p. 40). Initially "Heatley Avenue" was a peninsular projection into the east side of False Creek, and was included in the subdivided street grid; however, the area ended up becoming the site of a local dump (Ibid., p. 40). During its operation as a dump, it also became home to many squatters affected by the stock market crash and the economic depression (Ibid., p. 40). At one time the dump had more than 400 men living in its quarters (Ibid., p. 40). Assisted by the nearby First United Church, the men were also offered precarious work by the City, and some of the men were hired to help construct the Lions Gate Bridge (Ibid., p. 40). Due to the dumps proximity to existing residential developments, the odours and unsightly appearance made its operation short-lived, and it was closed in 1939 (Ibid., p. 40).

Capped with fill from city land near East Hastings, the dump was transformed into a park by 1947, and in 1948 trees and shrubs were planted and the site was graded to provide drainage (Ibid., p. 41). The park opened under the name 'False Creek Park' but changed in 1976 to 'Strathcona Park' due to its location within the Strathcona neighbourhood (Ibid., p. 41).

Figure 1.1-8 (Below)
View of False Creek Flats east of Main Street

Rail to Road

As the automobile industry grew, the area around False Creek Flats dependence shifted from rail to roads. Starting in the 1930s, and growing substantially “between 1945 and 1964, Vancouver began to experience a decline in the use and success of the railway” (Donald Luxton and Associates Inc., 2013, p. 42). This shift prompted the end of the BCER streetcars, which transitioned to buses in the 1950s, and personal automobiles allowed people to move further out to areas not serviced by the streetcars (Ibid., p. 42). The shift to automobiles had a significant impact on the False Creek Flats, as more industries became dependent on truck transport and businesses wanted to be located in areas with good access to roads and highways (Ibid., p. 42).

Terminal Avenue supported the transition of the False Creek Flats towards the truck and car movement, enabled by the Grandview Viaduct constructed between 1922 and 1938, across the north-south tracks that ran along Vernon Drive (Ibid., p. 42). The proximity to Hastings Street (which was a main highway at the time), the Great Northern Way, East Broadway, and the Grandview Highway supported both local industries and warehouses in the Flats. Many garages also set up shop in the area, which help support the demand for automobile repairs and maintenance (Ibid., pp. 42-43). As the dependence on rail continued to decline, the Great Northern Railway terminal no longer was needed and was demolished in 1965 (Ibid., p. 43). Although the road infrastructure took over the areas transport needs, rail infrastructure still dominates the character of the area.

Figure 1.1-9
Rail yards in False Creek Flats

Industrial Development

The transportation facilities, railway, and road networks attracted a variety of businesses to the False Creek Flats. In combination with offering large, flat parcels of land, the Flats has always been attractive to industrial uses, which could "process and deliver both raw materials and finished products" (Donald Luxton and Associates Inc., 2013, p. 47). Being located centrally in Vancouver also helped ensure businesses had access to the workers from the adjacent neighbourhoods, employing residents from the Strathcona, Mount Pleasant, and Grandview-Woodland neighbourhoods (Ibid., p. 51).

The road network of the area made it convenient to access the rest of the city, whether it be from Main Street, Terminal Avenue, Clark Drive, or the Grandview and Georgia viaducts (Ibid., p. 47). False Creek Flats has mostly been home to manufacturing, warehousing, and transportation-related industries. One of the first factories in the area was the Restmore Manufacturing Company, a mattress and bedroom furnishings business, located at 1000 Parker Street (Ibid., p. 47). Restmore strategically located right next to the rail lines, and had a rail spur leading directly to its building to help facilitate the easy loading and unloading of deliveries (Ibid., p. 47).

Also located in the flats was a neon production factory, which helped manufacture most of the neon signs in Vancouver's commercial districts (Ibid., p. 48). Its buildings were located from 260 to 270 Terminal Avenue, on the south side of the street, east of Main Street (Ibid., p. 48).

Other businesses located in the flats included: "the Massey-Harris Company (242 Terminal Avenue), the BC Valve Company (250 Terminal Avenue), a CNR Freight House, Johnston Storage, National Cart and Warehouse Company, the Pembina Coal Company, and the Corry Coal Company Sheds" (Ibid., p. 48). Industrial activity prevails today in the flats, including produce distribution companies along "Produce Row," located on Malkin Avenue, which established in 1951 with the arrival of T.P. Scott Ltd., the Chess Brothers, and Early Fruit Ltd. (Ibid., p. 48).

Other factories included Canada Packers, located at 750 Terminal Avenue, and General Paints at 900-950 Raymur Avenue, where the large parcels could accommodate the large floor plates these buildings demanded (Ibid., p. 49). A prominent company located in the flats also included Finning. Initially starting as Finning Tractor and Equipment Company Ltd, with a sales office in downtown Vancouver, the company transitioned to larger office space at 1296 Station Street, and then later moved its headquarters to a 36-acre site along the Great Northern Way in 1966 (Ibid., p. 51). In 1969, it became a publicly held company, and in 1987, the company changed its name to Finning Ltd. (Ibid., p. 51). Later in 2011, 18 acres of the site was donated to enable the Great Northern Way Campus, providing room for the University of British Columbia, Simon Fraser University, Emily Carr University of Art and Design, and the British Columbia Institute of Technology (Ibid., p. 51).

Community Gardens

Strathcona Community Garden and Cottonwood Community Garden are situated in the Flats, providing cultural and social places for nearby residents (Donald Luxton and Associates Inc., 2013, p. 51). Strathcona Community Garden was established in 1985 at the intersection of Prior Street and Hawks Avenue. Cottonwood Community Garden developed in 1991 near the intersection of Malkin Avenue and Raymur Avenue, at the southeast corner of Strathcona Park (Ibid., p. 51). Both community gardens are the largest in Vancouver (Ibid., p. 51).

As the False Creek Flats has already experienced different phases of economic, transportation, and technological shifts, it will continue to evolve as a productive hub of the city (Ibid., p. 51).

Figure 1.1-10
Cottonwood Community Garden

Figure 1.1-11
Strathcona Community Garden


Welcome to the Orchard
at Strathcona Community Garden
Strathcona Community Garden volunteers care for more than 300 varieties of organic fruit trees. The heritage fruit names, country of origin and date of discovery can be seen on labels in the espalier area.
For centuries, fruit growers have preserved unique species by grafting plant material from one tree to another. Varieties found here may serve as a genetic bank for future generations.
This is a teaching orchard. We experiment with growing methods and share what we learn. For mor mation on the orchard and how to join us, please visit our web
www.strathconagardens.ca |
DO NOT PICK THE FRUIT. We record yields to improve our understanding of the best varieties for this area. Also, with thousands of orchard visitors every year, stealing "just one" can add up.

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1.2 Geomorphology and Ecology

Figure 1.2-1
Georgia Depression Ecoprovince

Geomorphology of the Georgia Depression

Located in the Georgia Depression ecoprovince, Vancouver nestles "between the Vancouver Island Mountains," the Olympic Mountains, southwest side of the Coast Mountains, and the northeast side of the Cascade Ranges (Demarchi, 2011, p. 47). This ecoprovince is not only ecologically diverse but also contains most of British Columbia's population (Ibid., p. 47). The leeward side of the insular mountains of the Vancouver Island Ranges, as well as "the Olympic Peninsula of the Coast Range in Washington" influence the climate of the Georgia Depression (Ibid., p. 47). As air moves eastward down the leeward side of the Vancouver Island Mountains, it creates drier conditions as compared to the landscape closer to the Pacific Ocean, which tends to be cloudier and wetter. The Pacific Ocean and inshore waters moderate the temperatures within the Georgia Depression; however, with Vancouver being part of the Lower Mainland, the lack of "sufficient relief to force moist air to cooler elevations" results in reasonably dry conditions (Ibid., p. 48).

Overall the Georgia Depression is a large basin, which at one time "was covered by ice during the glacial periods" (Ibid., p. 48). As the glaciers retreated, ice flowed west "… from the Coast Mountains and eastward from [the] Vancouver Island Ranges…" coming together in the strait, then flowed south through to the "Juan de Fuca Strait and across the Puget Sound and Puget Lowlands in Washington" (Ibid., p. 48). Approximately 40 to 70 million years ago, after the glacial retreat, the majority of the lowlands were flooded with water, after having been compressed by the weight of the glaciers, and accumulated fine silt and clay material from the surrounding Coastal Mountains (Ibid., p. 48). These early coastal mountains were part of a chain of volcanoes along the west coast, also known as the Coast Plutonic Complex (Armstrong, 1990, p. 29). Regionally, Vancouver and surrounding areas are in a geologically active zone of subduction. The process of subduction and uplift is responsible for the picturesque landscape that surrounds Vancouver.

As the glaciers melted, areas where water moved faster tended to accumulate coarser sands and gravels, with some areas developing "moraines of mixed rock and soil." (Demarchi, 2011, p. 48) The Fraser Lowland sediment that forms the foundation for much of Vancouver and surrounding areas are made up of sandstone, mudstone, and conglomerates (Clague and Turner, 2010, p. 25). The continual uplift of the coastal mountains has caused this bedrock to tilt approximately 10 degrees to the south and is reflected in the surface profiles of Burnaby Mountain, Capitol Hill, and even Stanley Park (Ibid., p. 25). Further sediment accumulated atop of the Fraser Lowlands during different intervals of glacial retreat, and at the time, smaller hills, such as Burnaby Mountain, were islands within this basin, similar to the current Gulf islands (Armstrong, 1990, p. 17). During glacial retreats, sediment was carved out of the surrounding mountain valleys and redistributed in between the islands, creating much of the topography we see today (Ibid., p. 17).

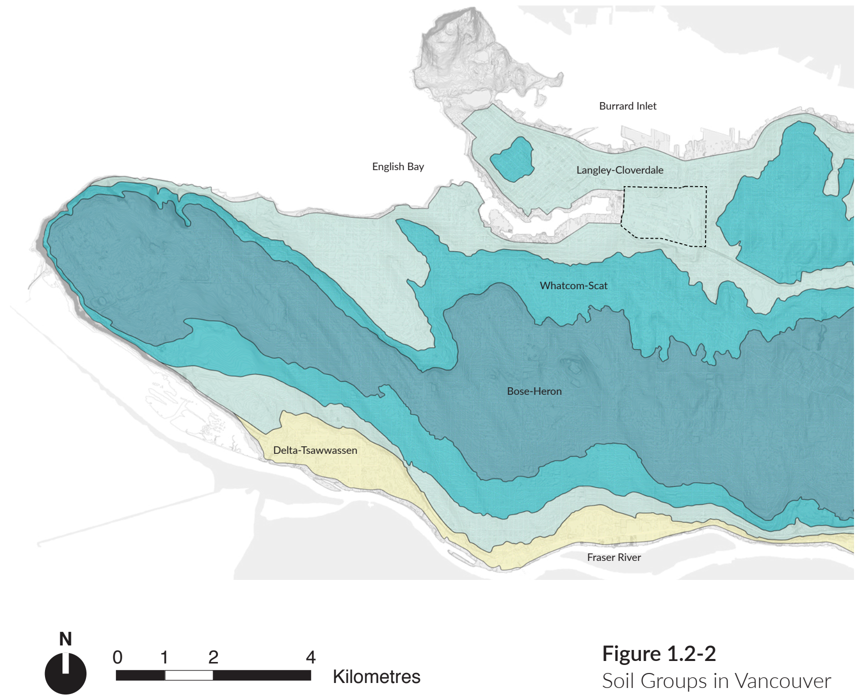


Figure 1.2-2
Soil Groups in Vancouver

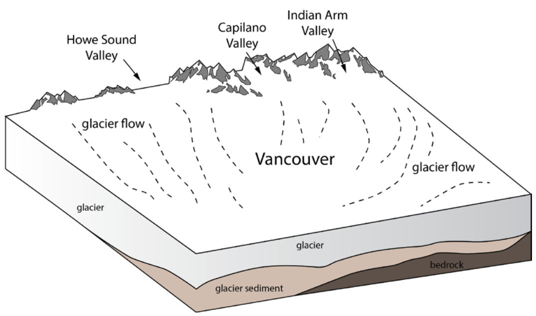


Figure 1.2-3 10,000 years ago, Fraser Glaciation

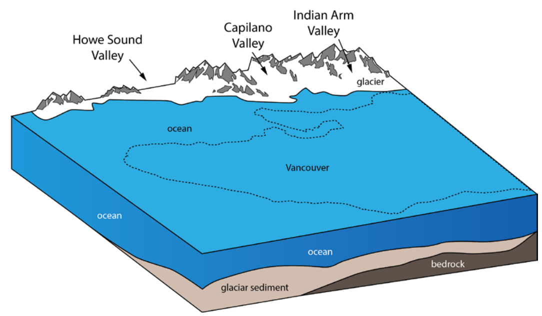


Figure 1.2-4 Land compressed remains underwater

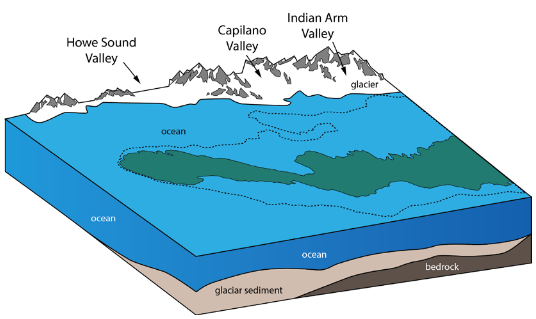


Figure 1.2-5 Bose-Heron soils

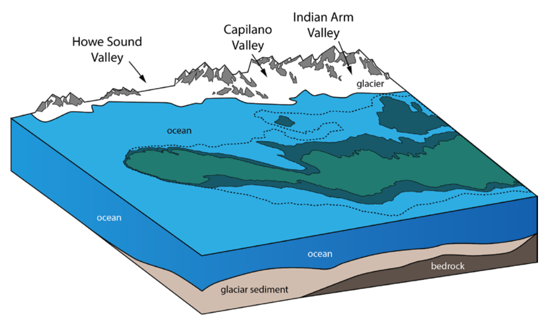


Figure 1.2-6 Whatcom-Scat soils

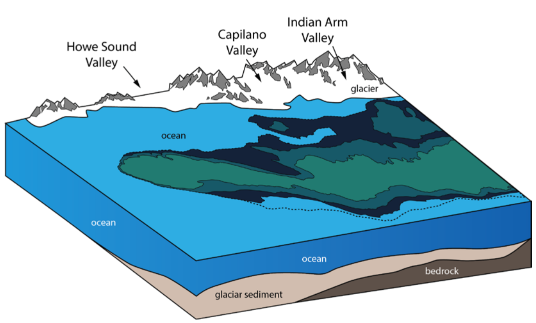


Figure 1.2-7 Langley-Cloverdale soils

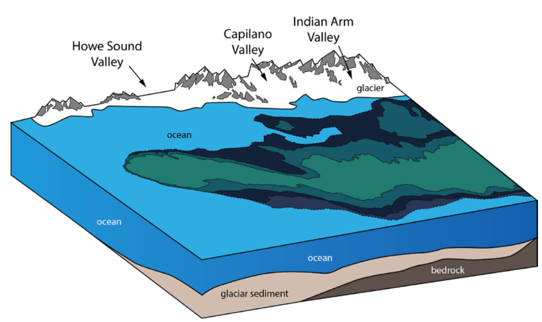


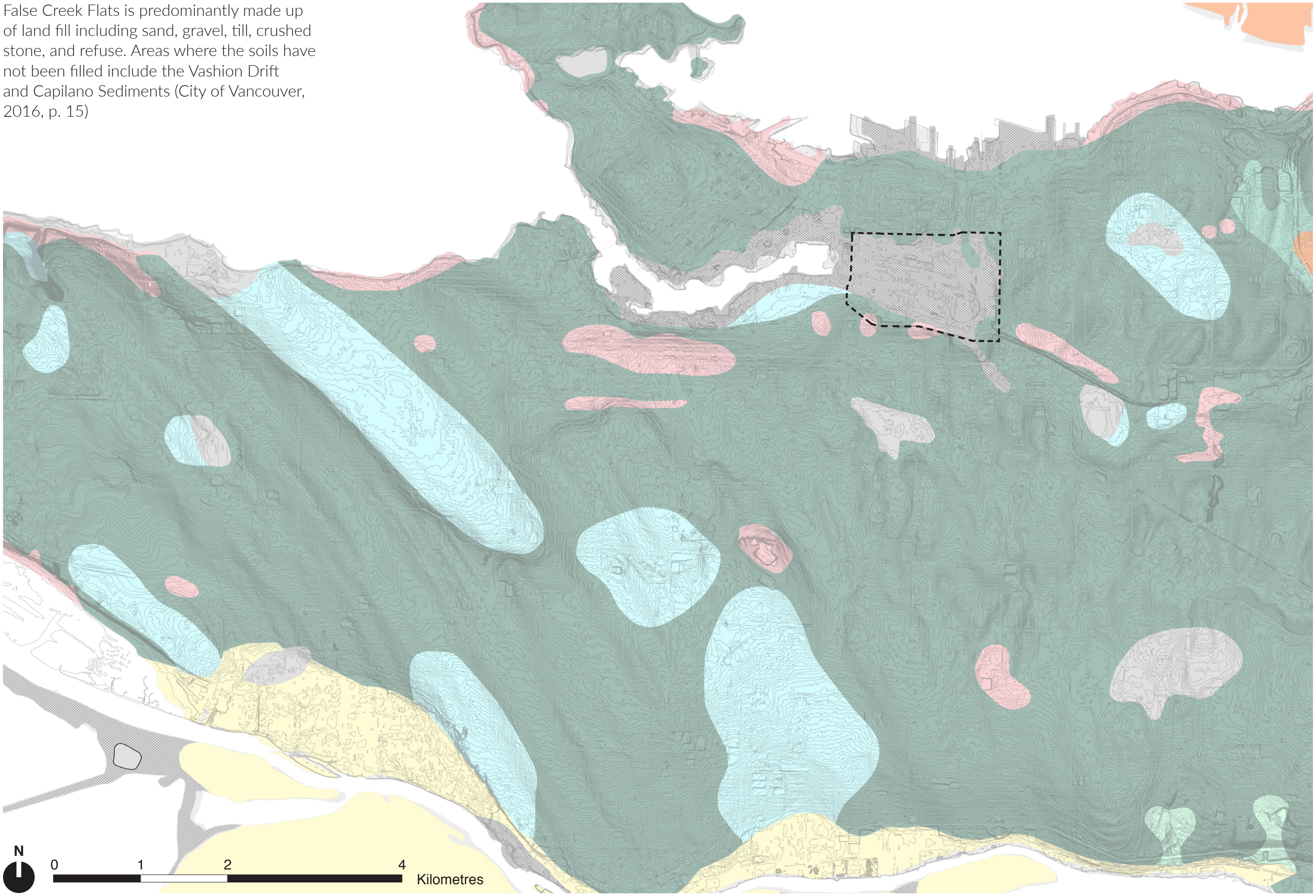
Figure 1.2-8 Delta-Tsawwassen soils

Over 10,000 years ago, Vancouver and the Fraser Lowlands were covered entirely by a two-kilometre thick glacier (Virtual Soil Science Learning Resources, n.d.). The weight of the glacier compressed the land underneath, leaving it under water after the ice melted.

Over time, through the process of isostatic rebound, the land began to rise out of the water. First with the Bose-Heron soils, which consists of areas in Vancouver greater than 65 metres above sea level (Ibid.) Afterward, the Whatcom-Scat soils began to rise, composed of the areas of the city between 35 and 65 metres above sea level (Ibid.). The Langley-Cloverdale soils followed and consist of areas of the city that are between approximately 3 and 35 metres above sea level (Ibid.). The last soils to rise included the Delta-Tsawwassen soils, which contain regions of the city that border the Fraser River (Ibid.). Although present-day False Creek Flats consists predominantly of fill material, it is underlaid by the Langley-Cloverdale soil management group.

Vancouver Soils

False Creek Flats is predominantly made up of land fill including sand, gravel, till, crushed stone, and refuse. Areas where the soils have not been filled include the Vashion Drift and Capilano Sediments (City of Vancouver, 2016, p. 15)



Quaternary

Postglacial

Landfill including sand, gravel, till crushed stone, and refuse

Bog, swamp, and shallow lake deposits

Marine shore sediments (beach deposits)

Lowland and mountain stream deltaic, channel fill, and overbank sediments

Deltaic and distributary channel fill sediments overlying and cutting estuarine sediments and overlain in the area by overbank sediments

Pleistocene

Capilano Sediments

Raised marine, deltaic, and fluvial deposits:

Vashon Drift and Capilano Sediments

Till, glaciofluvial, glaciolacustrine, and ice-contact deposits:

Pre-Vashon glacial, nonglacial and glaciomarine sediments

Liquefaction Susceptibility

Liquefaction can cause damage to infrastructure and buildings. With exposure to earthquakes, there are areas in Vancouver that are at risk of liquefaction, when silty and sandy soils act as a liquid due to the shaking of the ground (City of Vancouver, 2013).

The liquefaction diagram below indicates that all of False Creek Flats is within a 'very high' zone of liquefaction potential. The high liquefaction potential is likely due to the area being a historic tidal flat, as well as the fill that was added to the area. As such, any new development within the False Creek Flats should be designed to withstand seismic activity.

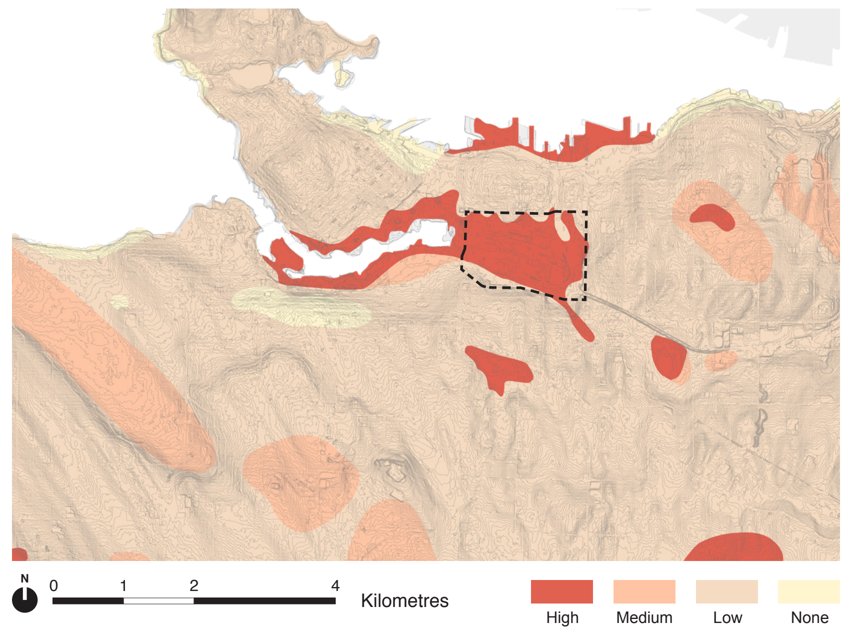


Figure 1.2-9 (Left and Above)
Surficial geology, soils map, and soil descriptions of Vancouver

Figure 1.2-10 (Above)
Vancouver liquefaction potential

Georgia Depression Ecoprovince

The east side of the Georgia Depression "… consists of a large delta that has filled in around low hills (Fraser Lowlands) and a narrow coastal plain of glacial deposits (Georgia Lowlands)…" (Demarchi, 2011, p. 48). Many streams and rivers cut through the valley from the mountains; however, the Fraser River is the dominant source of freshwater in the Georgia Depression ecoprovince (Ibid., p. 48).

Between the Lower Mainland and Vancouver Island is the "Strait of Georgia … a semi-enclosed estuarine environment that is strongly affected by [the] freshwater discharge … from the Fraser, … Skagit, Squamish, Cowichan, Puntledge, Campbell and Toba Rivers" (Ibid., p. 48). This marine environment provides sources of food and habitat for migratory birds that arrive along the Pacific Flyway.

The Georgia Depression contains four main marine ecosystems, including the nearshore zone, inter-island channels and sounds, extensive shallow areas, and estuaries (Ibid., p. 48). Nearshore zones are located around "the islands and [the] mainland, with [the] intertidal zone as the dominant interface between the land and the sea" (Ibid., p. 48). Steep shores and fast tidal currents characterize the inter-island channels, providing diverse habitats for flora and fauna (Ibid., p. 48). The shallow areas, provide "nutrient-rich environment[s]…" as do estuaries, which contain nutrient-rich waters supplied by rivers and streams (Ibid., p. 48). Estuaries in the Georgia Depression are rich habitats for migrating and wintering birds, and the Fraser River estuary is the largest in British Columbia (Ibid., p. 48). The Strait of Georgia supports marine ecosystems with depths that contain both a mesopelagic and epipelagic layer (Ibid., p. 48).

The Georgia Depression has one of the most extended growing seasons and supports a variety of plants. The fresh water from rivers that enter into the marine straits are characterized by estuary habitats, and the high tide areas to subtidal mudflats will typically contain "tufted hairgrass, fescues, rushes, seaside arrowgrass, silverweed, and sedges" (Ibid., p. 48). While riparian zones support "black cottonwoods, red alder[,] and big leaf maple," Douglas fir dominates the lower elevations (Ibid., p. 48). Trees in this ecoprovince typically include "Grand fir, western red cedar, and western flowering dogwood," and the forest understory typically supports "salal, dull Oregon-grape, sword fern, starflower, and mosses" (Ibid., p. 48).

Soils in the Georgia Depression are "moderately weathered, and become dry in the summer," and the fluvial soils that would have accumulated in the Fraser Valley, have been significantly disturbed by development (Ibid., p. 48). Most of Vancouver, including the False Creek Flats, is overdeveloped and has resulted in significant habitat loss. Although the urban Lower Mainland will likely only contain coyotes, the Georgia Depression does support a variety of wildlife. Rural and natural areas provide habitat for the Columbian Black-Tailed Deer while the intersection of the land and the sea offers habitat "for Harbour Seals and Northern and California Sea Lions;" and otters, mink, and raccoon habitats are found "in the estuaries along riverbanks and lakeshores" (Ibid., p. 49).

The Georgia Depression ecoprovince also provides habitat to many birds and fish in British Columbia, including "90% of all bird species known to occur in the province," and "60% of the bird species ... known to breed in British Columbia" (Ibid., p. 50). Some of the more prominent birds include "Pacific Loon, Western Grebe, Brandt's Cormorant, Common and Barrow's goldeneyes, Surf, White-winged and Black scoter, Greater and Lesser scaup, Thayer's and Glaucous-winged gulls, Common Murre, and Marbled and Ancient murrelets" (Ibid., p. 49). Some of the wintering shorebirds include Black Turnstone and Surfbird (Ibid., p. 49).

The Georgia Depression hosts a variety of fish. Marine waters support "rockfish, flounder, spiny dogfish, Pacific herring, and lingcod," and fish that develop in freshwater but mature in saltwater include "Pacific salmon, steelhead, coastal cutthroat trout, and eulachon" (Ibid., p. 50). Fish that live their lives only in freshwater include "pumpkinseed and smallmouth bass, ... native peamouth chum and threespine stickleback," while fish that move freely between marine and freshwater environments include "green sturgeon, Dolly Varden char, (bull trout ... in the Lower Mainland), and Coast Range sculpin" (Ibid., p. 50).

The Georgia Depression also contains four ecoregions and seven ecosections. Vancouver is located in the Lower Mainland Ecoregion, and within the Fraser Lowland Ecosection.

The Lower Mainland Ecoregion is characterized by greater precipitation "towards the Coast Mountains and Cascade Ranges ... [with a] slight rainshadow on the lowlands and the Fraser River delta" (Ibid., p. 54). Although the area is generally flat, it contains "some higher ridges and hills ... above the low land surface" (Ibid., p. 54).

False Creek Flats is located in the Fraser Lowland Ecosection, which includes "the Fraser delta, estuary, lowlands, and associated uplands" (Ibid., p. 54). False Creek Flats, however, is located within the 'uplands' area. Although the base of this Fraser Lowland Ecosection is primarily granitic rocks that are part of the Coast Mountains, there is almost 3,000 metres of sediment beneath the Ecosection, and the Fraser Delta is still growing outwards from sediment from BC's interior, brought down the Fraser River (Ibid., p. 54). Other large streams on the north side of the valley include Harrison, Stave, Pitt, and Coquitlam (Ibid., p. 54). Adjacent to the Fraser Lowland Ecosection to the west is the Strait of Georgia Marine Ecosection, which interfaces with the Fraser River estuary, and the intertidal and nearshore zones up the Burrard Inlet (Ibid., p. 54).

The weather in Vancouver is influenced by the mountains as well as air from southern and northern regions. The air from the Pacific Ocean can get caught in the adjacent mountains, which brings rain and snow into the mountainous regions; however, the lowlands are influenced by air from the south, which creates warm-dry conditions that generate a Mediterraneanlike atmosphere (Ibid., p. 54). Cold arctic air from the north can sometimes result in snow storms in the lowlands, although this tends to occur infrequently (Ibid., p. 54).

The vegetation in the low-lying areas of the Fraser Delta include the dry Coastal Western Hemlock forests, whereas the higher regions contain the dry maritime Coastal Western Hemlock Forest biogeoclimatic zones (Ibid., p. 54). Historically the lowlands supported dense conifer forests before clear-cutting diminished their presence in the latter part of the 1800s (Ibid., p. 55).

British Columbia's most significant urban population also exists within the Fraser Lowland Ecosection, and an extensive road network exists within the area (Ibid., p. 55).

Coastal Western Hemlock Zone

False Creek Flats is located in the Coastal Western Hemlock (CWH) biogeoclimatic zone, and more specifically in the dry, maritime, subzone. This zone generally occurs in the "...low to middle elevations ... west of the coastal mountains, along the entire British Columbia coast" (Pojar et al., 1991, p. 96). The CWH zone extends from sea level to roughly "900 [metres] on windward slopes in the south and mid-coast (1050 [metres] on leeward slopes), and 300 [metres] in the north" (Ibid., p. 96). CWH is considered one of the rainiest zones in BC, with the mean annual precipitation for the zone being 2,228 millimetres; however, it ranges from 1,000 to 4,400 millimetres throughout the entire zone (Ibid., p. 96). Based on reports by the City of Vancouver (2016, p. 11), the annual precipitation in False Creek Flats ranges from 1,400 to 1,500 millimetres.

The Western Hemlock is most common in forests in this zone, and tends to regenerate quickly "under the canopy of mature stands;" however, "Grand fir, western white pine, and bigleaf maple" tend to grow in more southern areas, where the temperature is warm and dry (Pojar et al., 1991, p. 96). Red alder often grows on disturbed sites, and black cottonwood occurs on extensive floodplains and along large rivers (Ibid., p. 96). Sitka spruce is found throughout the CWH zone; however, in southern areas, it is often located in areas along rivers or floodplains and exposed beaches (Ibid., p. 96).

Figure 1.2-11
Topographic relationships in the dry, maritime, Coastal Western Hemlock subzone

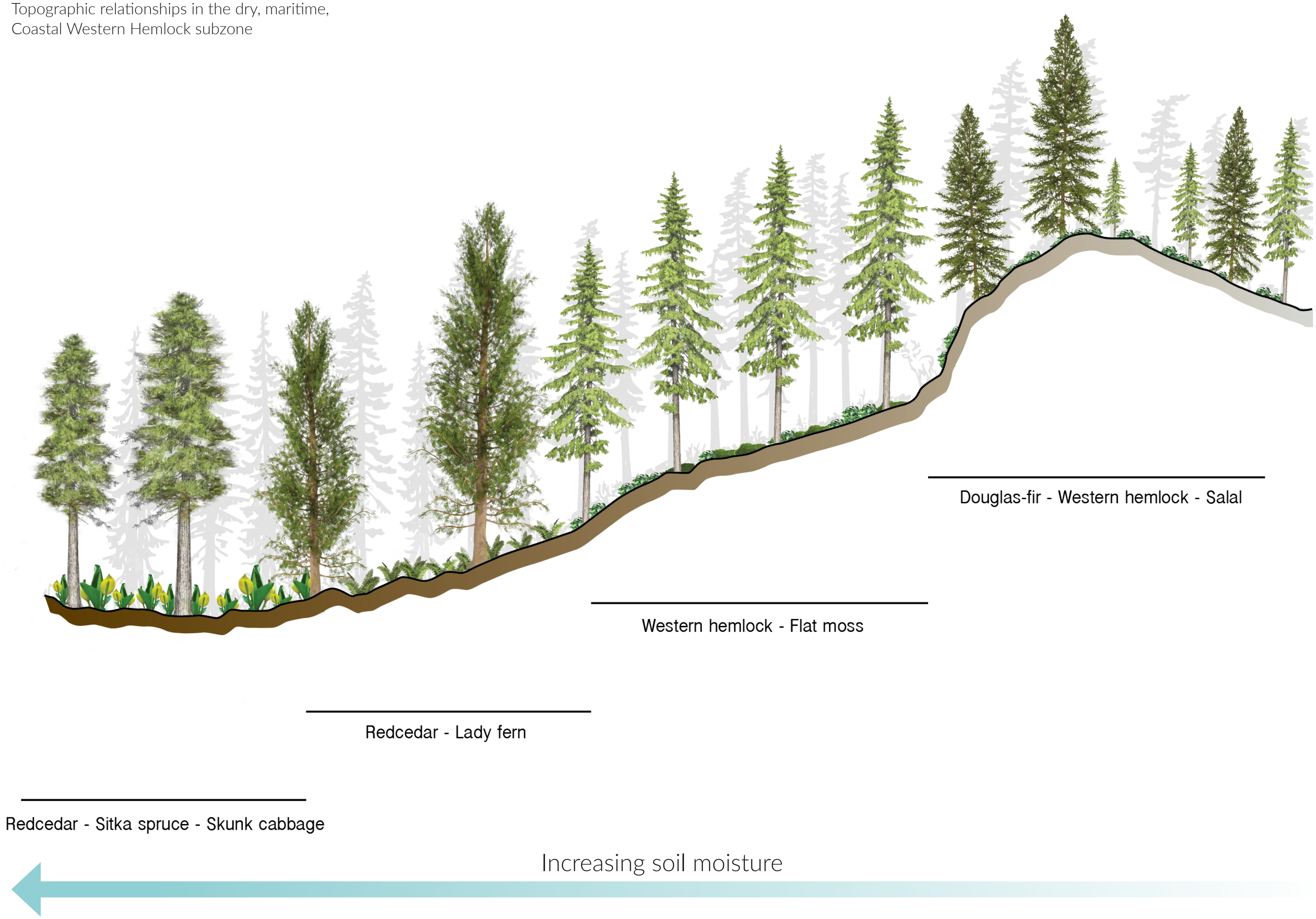


Figure 1.2-12
Skunk cabbage, ferns, and moss near stream, Capilano Park


Figure 1.2-13
Vine maple tree, Capilano Park

1.3 Topography and Hydrologic Systems

Topography of Vancouver

The contours on this map are shown at one metre intervals. Historically False Creek Flats was a tidal flat and was filled in to accommodate rail yards. Most of the area is between two and four metres above sea level. Only when the area approaches Clark Drive and Great Northern Way does it start to gain significant elevation.

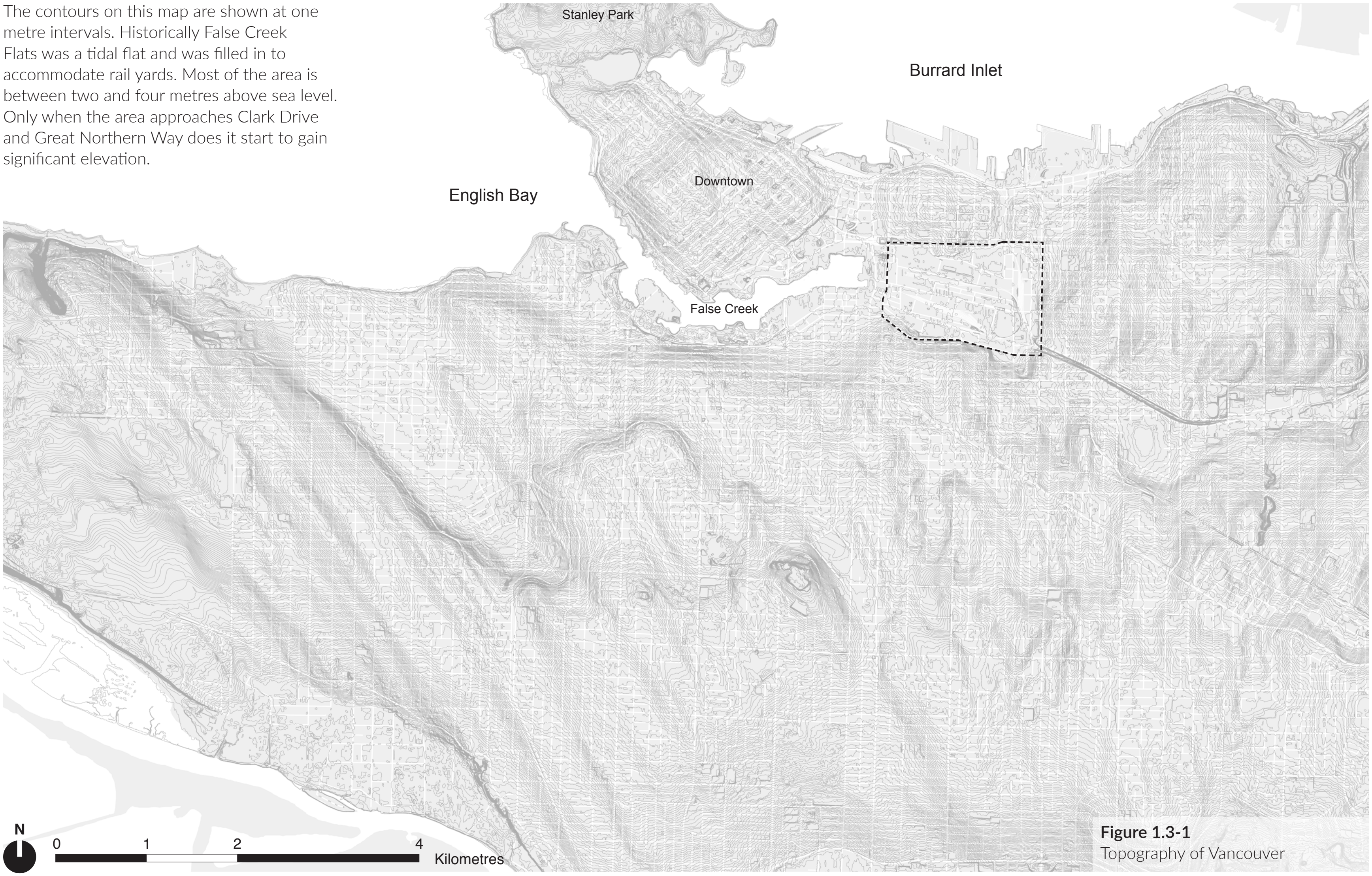


Figure 1.3-1
Topography of Vancouver

Topography of False Creek Flats

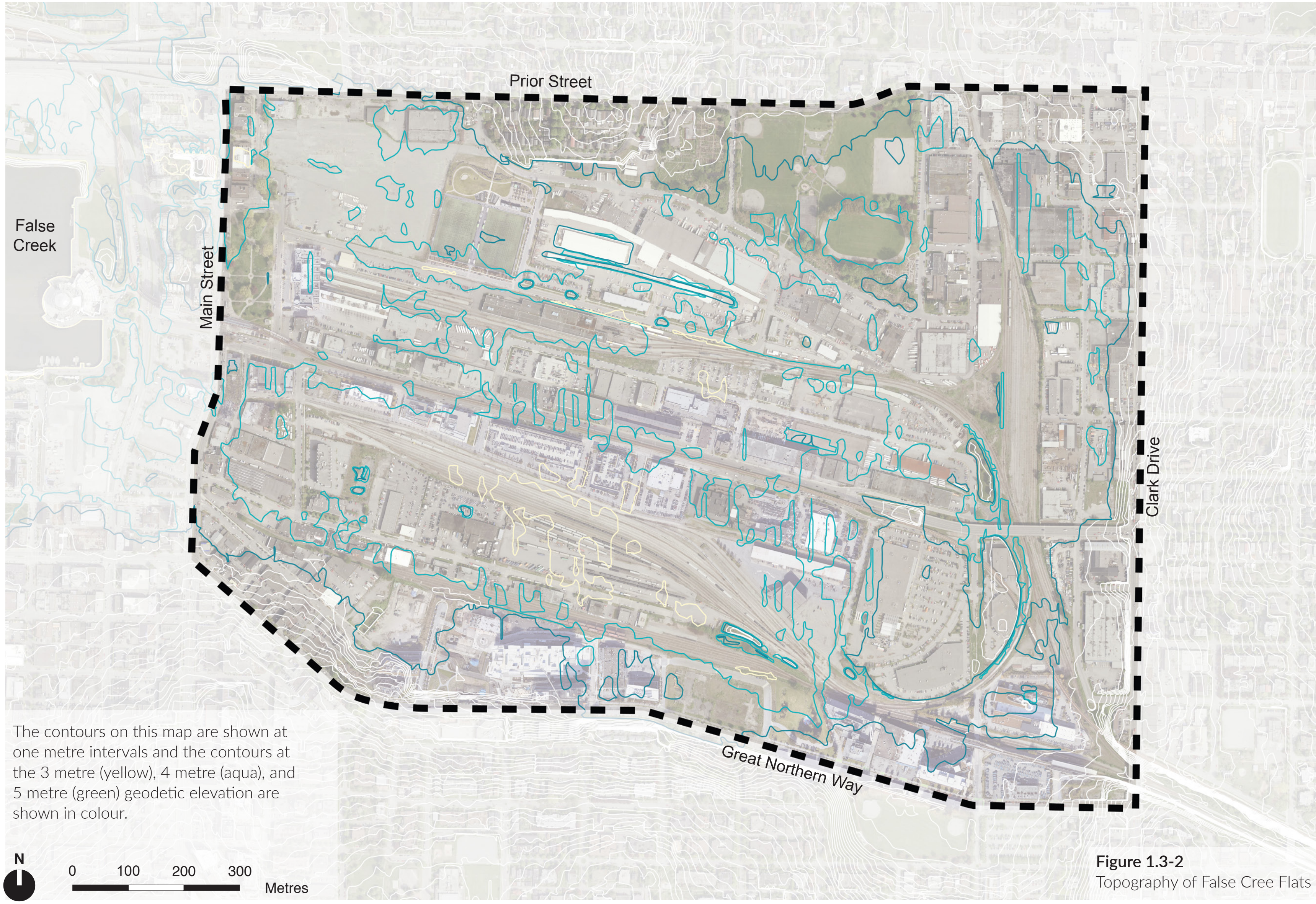


Figure 1.3-2
Topography of False Cree Flats

Terminal Avenue Cross-Section

Terminal Avenue dissects False Creek Flats from west to east. As illustrated in this cross-section, there is very little change in elevation along Terminal Avenue until approximately Glen Drive.

The blue dashed line represents sea level, showing that the False Creek Flats area does not have a significant buffer against future sea level rise. Even if buildings are built with a higher flood construction elevation line, people may have difficulty moving around the area if flooding did occur.

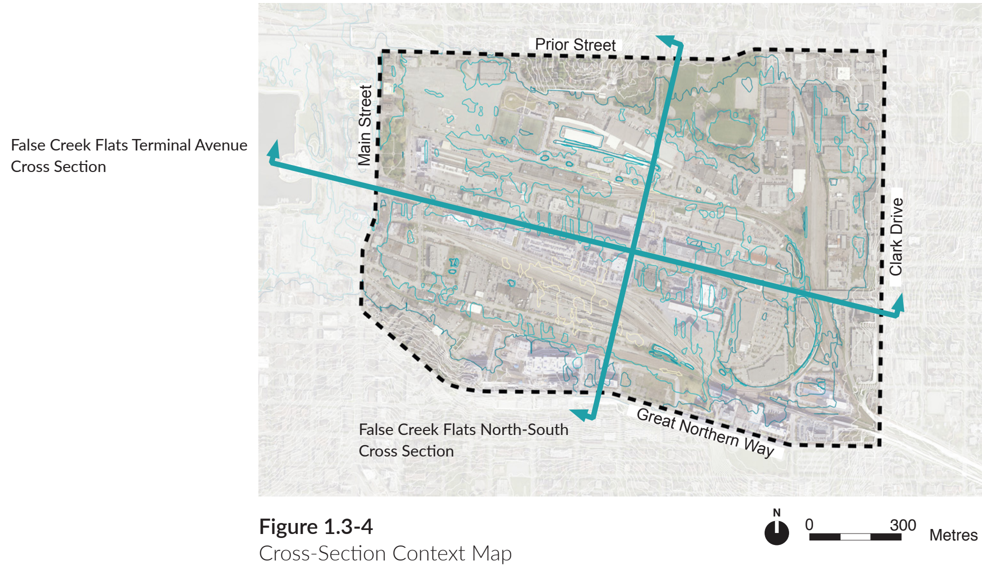


Figure 1.3-4
Cross-Section Context Map

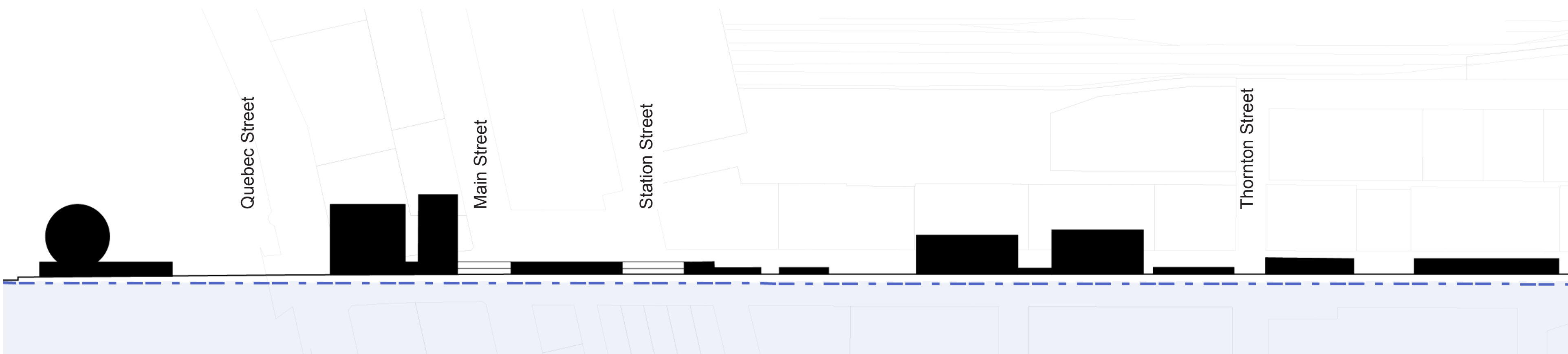


Figure 1.3-3
False Creek Flats Terminal Avenue (North Side) Cross-Section
(Not to scale)

North-South Cross-Section

The North-South cross-section also demonstrates how flat the topography is in False Creek Flats. Although there is a rise in elevation closer to Great Northern Way, the majority of the landscape is relatively flat. The buildings in False Creek Flats also have a relatively low profile. This may be due to the industrial character of the area; however, it also allows for views to the mountains to the North.

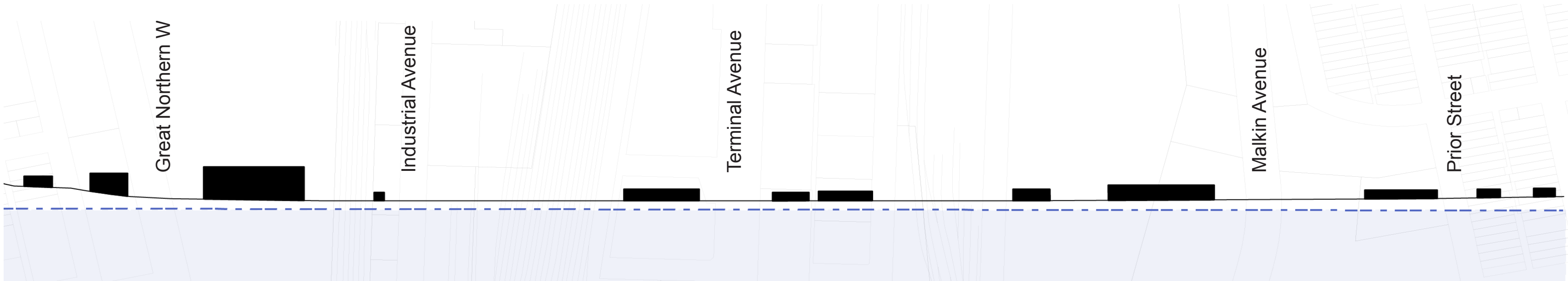
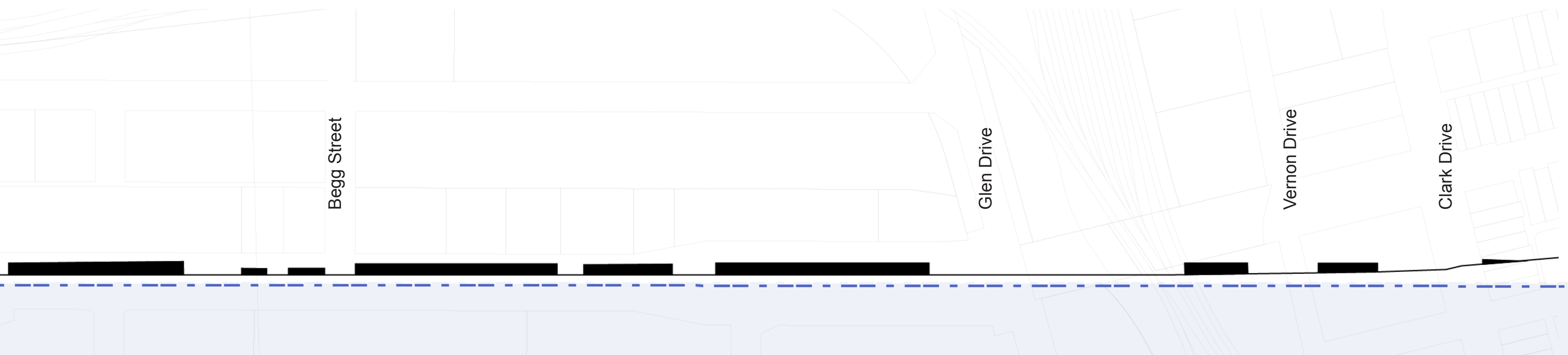


Figure 1.3-5
False Creek Flats North-South Cross-Section
(Not to scale)



Lost Streams and Historic Shoreline

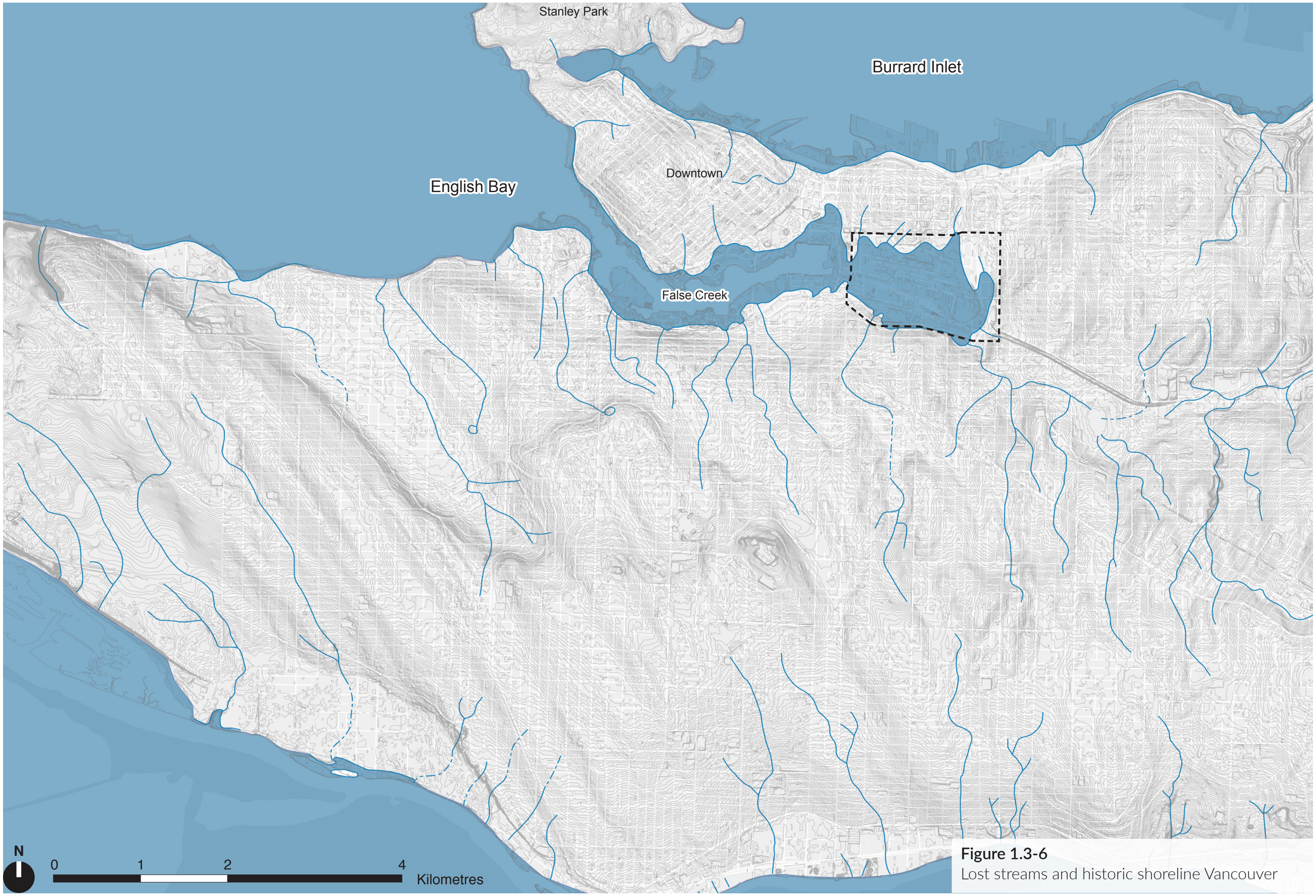


Figure 1.3-6
Lost streams and historic shoreline Vancouver

Historic Shoreline Superimposed Over False Creek Flats

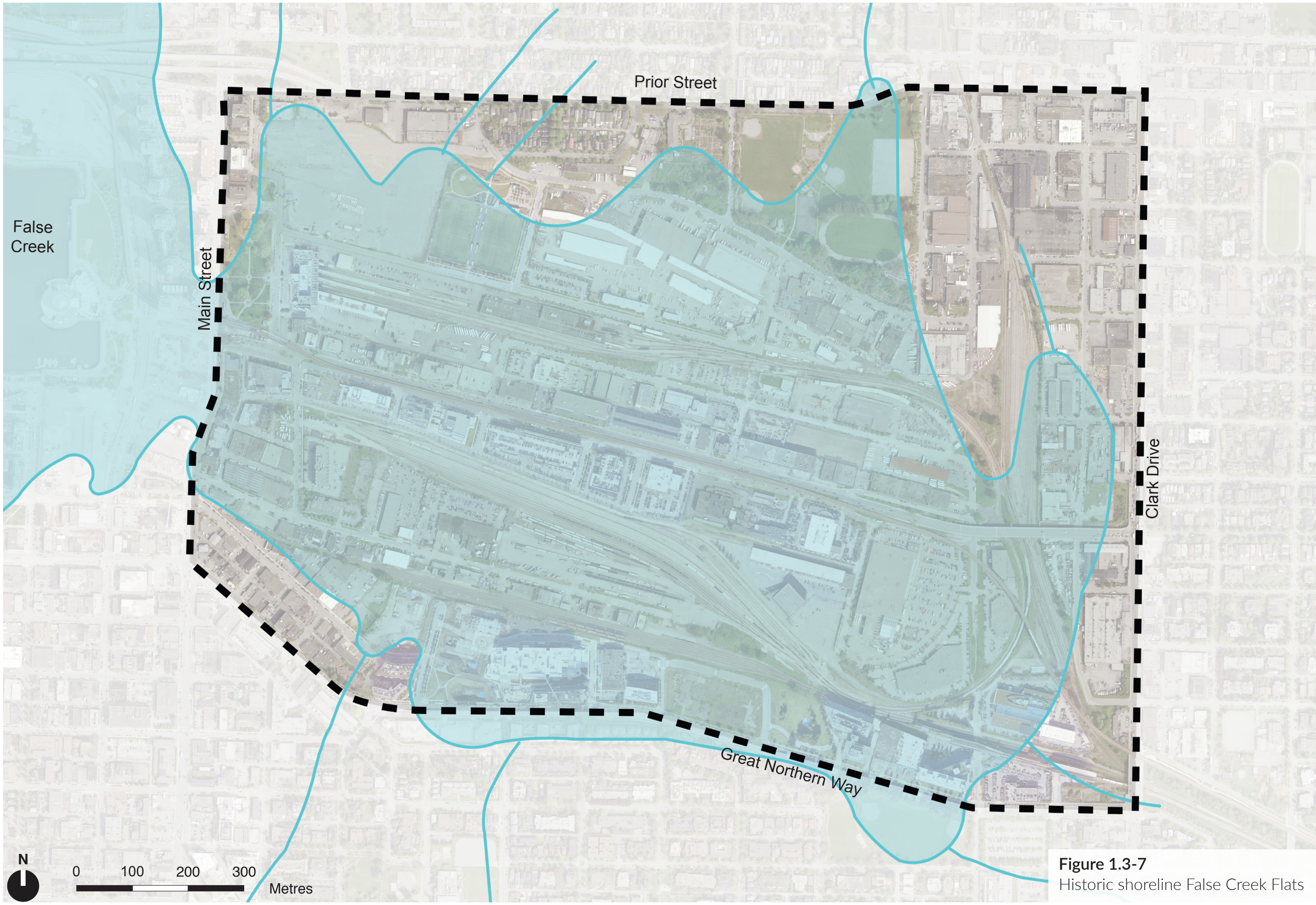


Figure 1.3-7
Historic shoreline False Creek Flats

Stormwater Management Areas and Sewer Network

False Creek Flats is contained within the Terminal stormwater management area (City of Vancouver, 2016, pp. 12-13). Most of Vancouver's storm water is managed by underground infrastructure, which will be put under greater pressure as global warming brings more intense, and frequent storms.

There are only two above ground watersheds that have live streams, which include Still Creek and Musqueam Creek (Ibid, p. 12-13).

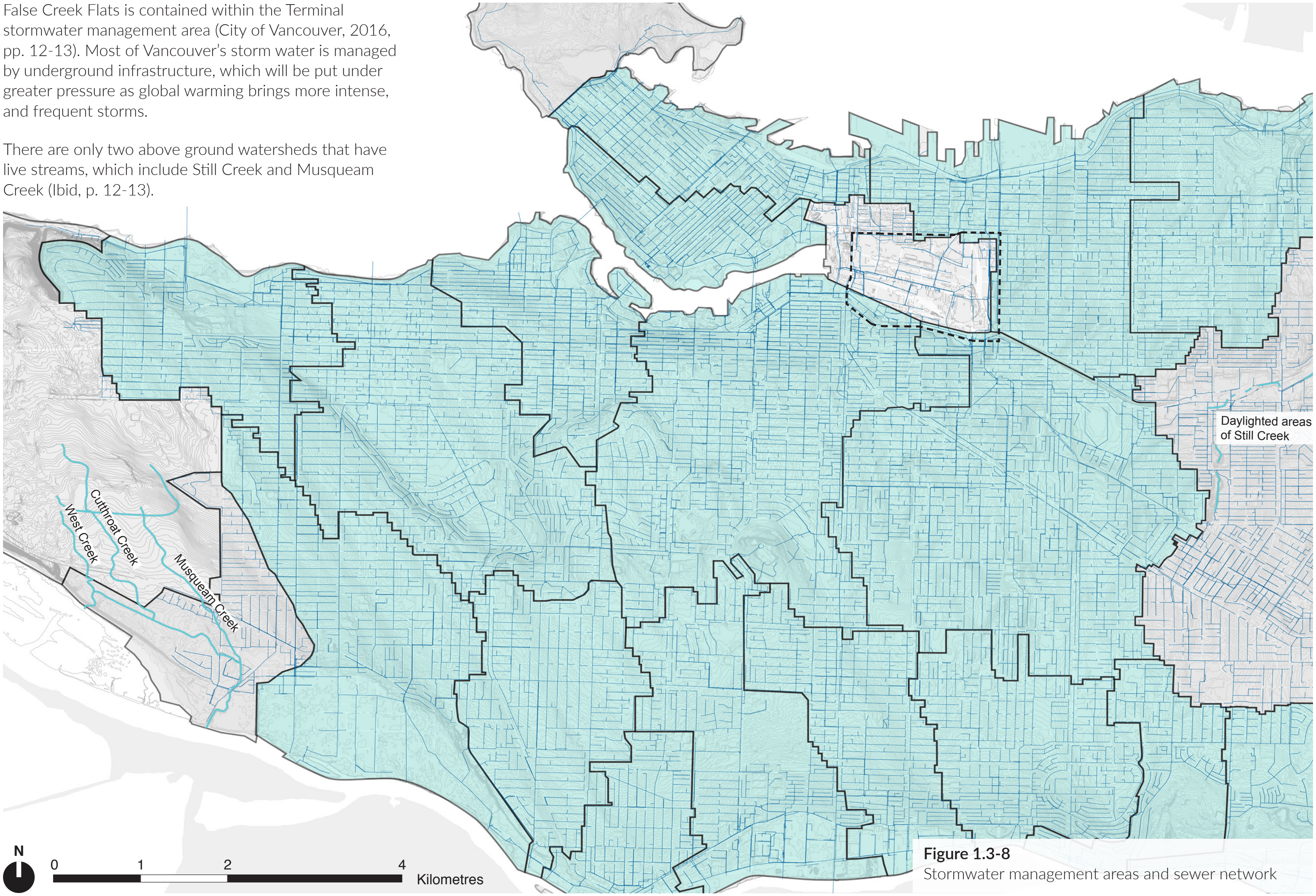
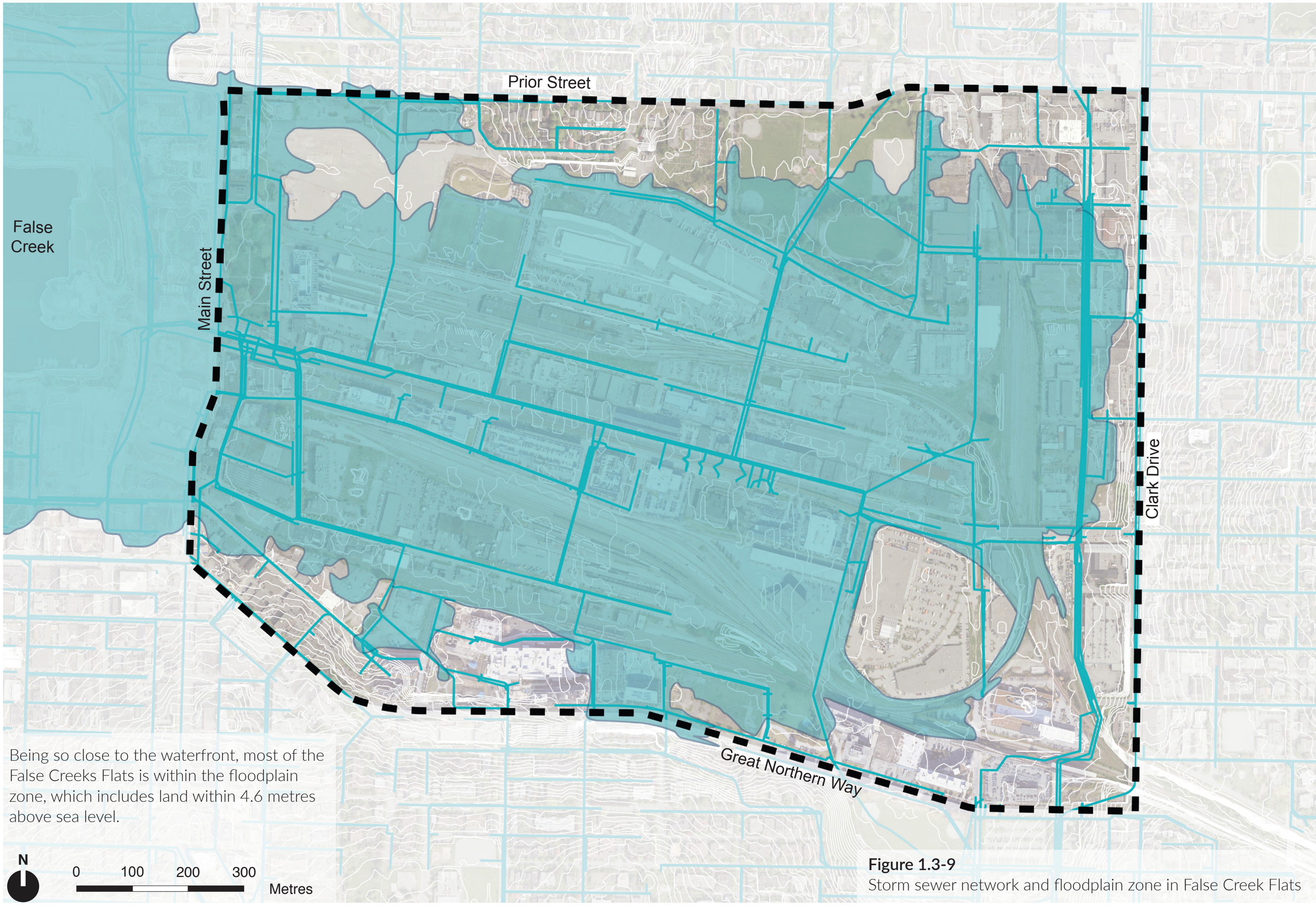


Figure 1.3-8
Stormwater management areas and sewer network

Storm Sewer Network and Floodplain Zone



Being so close to the waterfront, most of the False Creeks Flats is within the floodplain zone, which includes land within 4.6 metres above sea level.

Figure 1.3-9
Storm sewer network and floodplain zone in False Creek Flats

Precipitation

Vancouver on average receives the most precipitation between October and March. Reviewing the historical monthly precipitation rates, the fall of 2010 appears to have had an exceptional amount of precipitation in comparison to other years.

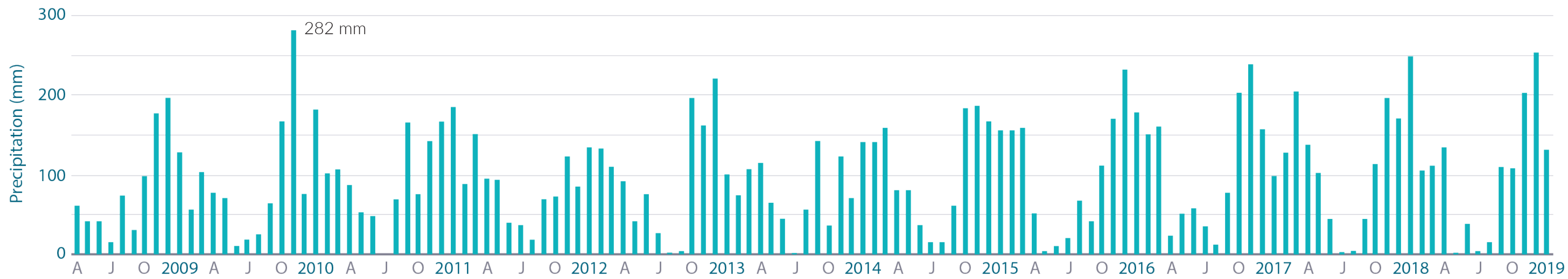


Figure 1.3-10
Vancouver monthly precipitation 2008 - 2018

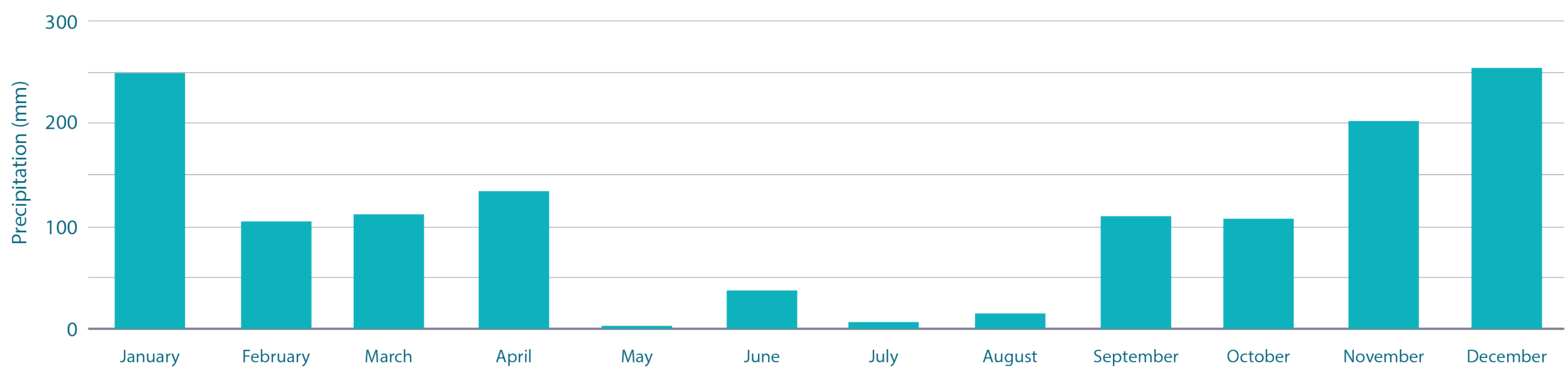


Figure 1.3-11
Vancouver monthly precipitation - 2018

Average Annual Precipitation Bands (Isohyets - mm)

The Isohyets shown on the right indicate the average annual precipitation for different regions in Vancouver. Based on this diagram, False Creek Flats falls between 1400 mm to 1500 mm of annual precipitation.

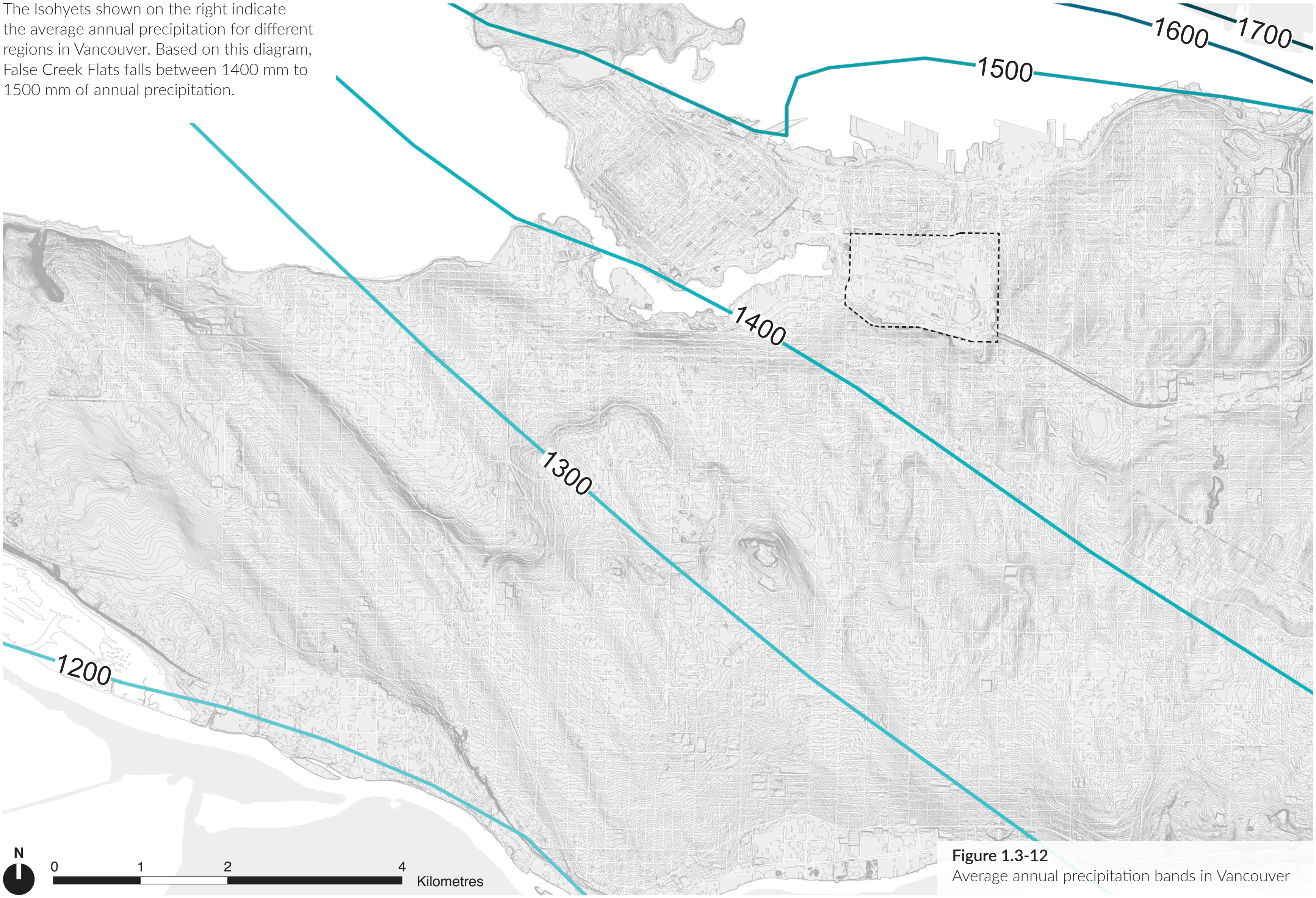


Figure 1.3-12
Average annual precipitation bands in Vancouver

1.4 Land Use and Development Plans

Economy and Land Use

False Creek Flats is in a desirable location with proximity to downtown, the ports, rail, and water. Historically the area shifted from a tidal flat to being lined with sawmills and other industries, to being filled in to accommodate rail yards. Currently, the district has evolved to support over 600 businesses that serve the local economy (City of Vancouver, 2017, p. 6). It is a hub of food distribution industries, manufacturing industries, and a mix of warehouses to the north of the Flats. Also existing within the Flats are automotive dealerships and other commercial and retail establishments centrally located along Terminal Avenue and extending along Vernon and Glen Drive. Some institutional uses, such as fire rescue and police services are also located centrally. Residential uses and an educational campus for the arts, including the new location for the Emily Carr University of Art and Design are located on Great Northern Way.

Currently, False Creek Flats is predominantly zoned for industrial uses. Along Main Street, there is a mix of commercial uses with some existing hotels, and along Great Northern Way towards the south is the Great Northern Campus, which includes the new campus for Emily Carr University. There are also three distinct parks within False Creek Flats, including Thornton Park, Trillium Park, and Strathcona Park.

The area is predominantly defined by the rail yards that dissect

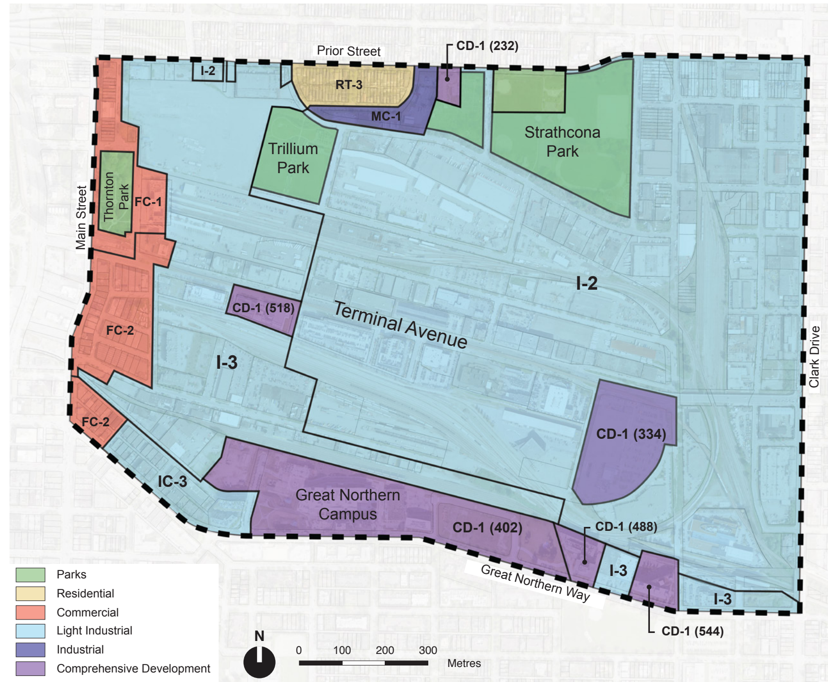


Figure 1.4-1
Zoning of False Creek Flats - 2018

The majority of the area is zoned for industrial, with institutional uses along Great Norther Way and commercial uses along Mains Street and residential and open space uses closer to Prior Street.

the Flats, which impedes the location for new development as well as movement throughout the area. With increasing pressure to develop, as well as regional policies to increase employment from 8,000 jobs to more than 30,000 by 2040 (Ibid., p. 22) the City of Vancouver has prepared a plan to shape the future of the False Creek Flats.

False Creek Flats Area Plan

The False Creek Flats Area Plan (City of Vancouver, 2017, p. 12) identifies four character areas that define the Flats: the Health Hub, Creative Campus, Terminal Spine, and Industrial Back of House to help guide development to meet its objectives.

- The Health Hub will be the future home to the new St. Paul's hospital and a variety of health services (Ibid., p. 12).
- The Creative Campus accommodates the new Emily Carr campus, which will support the emergence of innovative technologies and industry in the Flats (Ibid., p. 13).
- The Terminal Spine and the Back of House area will support the development of industrial-office activities and will continue to support production and distribution industries that are connected to the downtown, the ports, and adjacent districts such as the Grandview-Woodland area (Ibid., p. 13).

Institutional services will be maintained to support emergency services to the city; however, the City of Vancouver, plans to restrict further expansion of auto dealerships and self-storage industries within the area (Ibid., p. 15).

The False Creek Flats Area Plan leverages the presence of the educational institutions for economic growth, and the expansion of the Millennium Line on Broadway will enhance the connectivity of the Flats to downtown, the University of British Columbia, Simon Fraser University, Vancouver General Hospital, and other areas (Ibid., p. 22).

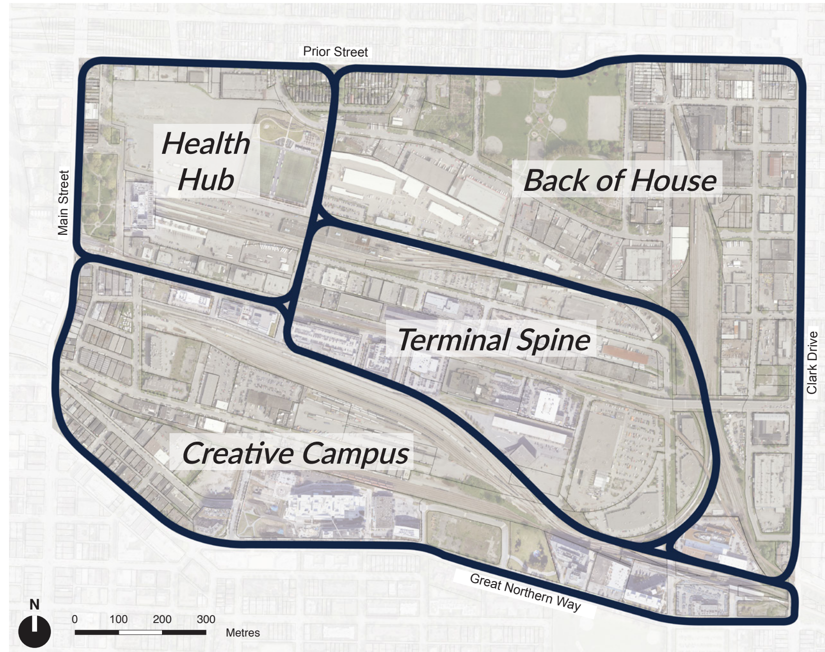


Figure 1.4-2
Proposed character sub-areas for False Creek Flats

Some of the False Creek Flats Area Plan principles include:

- Modernize the district into a creative economy
- Maintain and intensify industrial land for core and back-up functions
- Enhance and build on the unique character of the area
- Expand and improve the public space network
- Improve connectivity and mobility
- Support and enhance the presence of arts, culture, and food
- Create affordable spaces for emerging businesses
- Maintain and improve the efficiency of rail
- Reintroduce natural systems to build a resilient and healthy environment
- Support innovative housing that support economic initiatives (Ibid., p. 7).

Chapter 2
Flood Risk and the False Creek Flats

2.1 Factors Contributing to Flood Risk

- Flood Risks to the False Creek Flats
- Astronomical Tides
- Inverted Barometer Effect
- Storm Surge and Storm Tides
- Wind Setup
- Wave Setup and Wave Runup
- Pacific Decadal Oscillation and El Nino Southern Oscillation Climate Variations
- Sea Level Rise
- Flooding Hazards and Vulnerabilities
- Flood Construction Levels
- Flood Extent Map of False Creek and False Creek Flats
- Flood Risk and Stormwater Capacity

2.2 Flood Protection Options and Evaluation

- Flood Protection Options and Evaluation
- ‘Protect’ Option 1 - Flood Protection Provided by a Sea Barrier at the Burrard Bridge
- ‘Protect’ Option 2 - Flood Protection Provided by a Raised Seawall along False Creek
- ‘Protect’ Option 3 - Flood Protection Provided by a Partial Dike at Quebec Street
- Analysis of Flood Protection Options for False Creek

Figure 2.0 - 1
Sea Level Rise Public Art, False Creek

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2.1 Factors Contributing to Flood Risk

Flood Risks to the False Creek Flats

False Creek Flats will be at risk of flooding due to sea level rise and changes to hydrological systems. As sea level continues to rise, there will be times during storm and high tide events where sea water will over-top the seawall at the World of Science and inundate low-lying areas of the False Creek Flats. Further complicating matters, the storm sewer network will not have the capacity to collect stormwater and convey it to False Creek.

Two coastal flood risk assessment reports prepared for the City of Vancouver were reviewed to gain a better understanding of the potential extent of flooding in the False Creek Flats (Northwest Hydraulic Consultants, 2014; Compass Resource Management Ltd. and Ebbwater Consulting, 2015). These reports identify areas vulnerable to flooding and high-level options to reduce or adapt to flood risks.

The Phase 1 report indicates physical processes that influence ocean water levels, including tides, storm surge, wave setup, wind waves, climate variations due to the Pacific Decadal Oscillation and El Nino Southern Oscillation, and sea level rise. The report also focuses on identifying the hazards and vulnerabilities the City of Vancouver will be exposed to as a result of sea level rise (Northwest Hydraulic Consultants, 2014, p.1) and established the current flood construction level (FCL) that applies to the floodplains in the False Creek Flats. The Phase 2 report identifies more specific risks in for the flood risk zones, including False Creek and the False Creek Flats, and high-level options to mitigate the flood risks that can inform future land use and policy decisions (Compass Resource Management Ltd. and Ebbwater Consulting, 2015).

The following sections provide a summary of the factors that influence sea levels, which is then followed by an identification of the flood risks that the False Creek Flats will face with a one metre rise in sea levels by the year 2100.

Astronomical Tides

Sea levels are affected by the tides. In Vancouver, there are two high tides and two low tides per day. The distance between the high tide and the low tide is called the tidal range, and the height of the tides in Vancouver relates to both the earth's rotation and Vancouver's position in relation to the sun and the moon. When the moon is above Vancouver or on the opposite side of the earth, high tide occurs. The tidal pattern of two high tides and two low tides during a day is known as semidiurnal (Hicks, 2006, p. 42); however, Vancouver has one higher high tide and one higher low tide per day, reflecting a mixed semidiurnal tidal pattern. The earths tilt, rotation, and position in relation to the sun and the moon influence tidal patterns.

Both the sun and the moon exert gravitational forces on the earth; this force in combination with the centrifugal motion of the earth's rotation influence how tides move. Tides respond more significantly from the gravitational force between the earth and the moon, due to the moon's proximity to the earth being closer than the earth to the sun. When the moon, the earth, and the sun are in alignment, this creates what we know as spring tides. During this time, the gravitational forces of both the moon and the sun generate a higher high tide. When the moon and the sun are at right angles to the earth, this creates neap tides. During this phase, the gravitational forces somewhat cancel each other out and cause lower high tides. The relationship between the position of earth, the moon, and the sun correspond with the lunar phases of the moon's orbit, which occurs over a period of 29.5 days (Pugh, 2004, p. 31). During the new moon and full moon phase, the moon aligns with the sun and create spring tides.

Other factors that influence tides include the position of the earth on its ecliptic orbit (orbit around the sun) and the position of the moon on its elliptic orbit around the earth. Both the moon and the earth have elliptical orbits, and at certain times the moon is closer to the earth, and the earth is closer to the sun. When the moon approaches its closest distance to the earth, this is known to as perigee (Hicks, 2006, p. 15). When it is furthest away from the earth, it reaches its apogee (Ibid., p. 15). Similarly, when the earth is closest to the sun, it reaches perihelion, and when its further away it reaches its aphelion (Ibid., p. 14). The earth's perihelion occurs in January, and aphelion occurs in July. The moon reaches its apogee and perigee once a lunar month. As the moon approaches perigee, tides can be slightly higher, mainly if this occurs during a new or full moon phase.

Another factor that affects the height of tides is the declination of the sun and the moon. The position of the sun to the earth's equatorial plane varies throughout the seasons approximately between 23.5°N in June to 23.5°S in December (Pugh, 2004, p. 40). The moon declination varies over the lunar month and is about 5° above and below the ecliptic of the sun (the earth's orbit around the sun). Further complicating the effect on tides is the rotation of where the moon passes through the ecliptic during its orbit, which occurs over a period of 18.6 years. This nodal regression causes "the moon to vary in its maximum

Figure 2.1-1
Tidal relationship between spring tides and the lunar phase (based on Crooks, 2011).

Spring tides occur when there is alignment between the moon, earth and the sun.

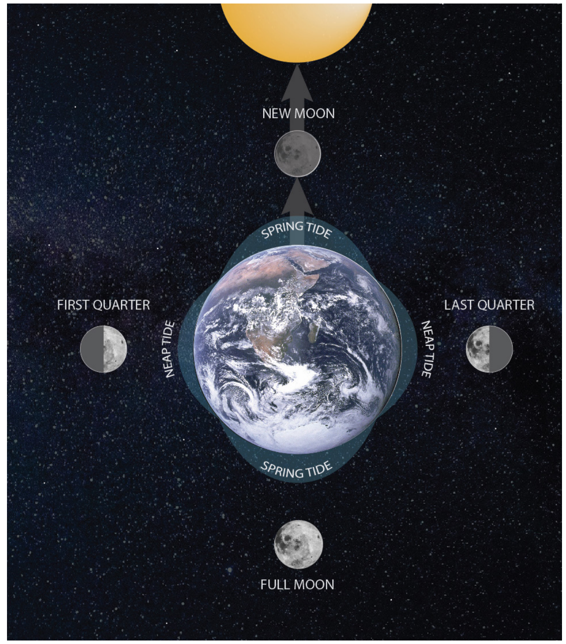


Figure 2.1-2
High and low tide relationship with the position of the moon in relation to the earth (based on Crooks, 2011).

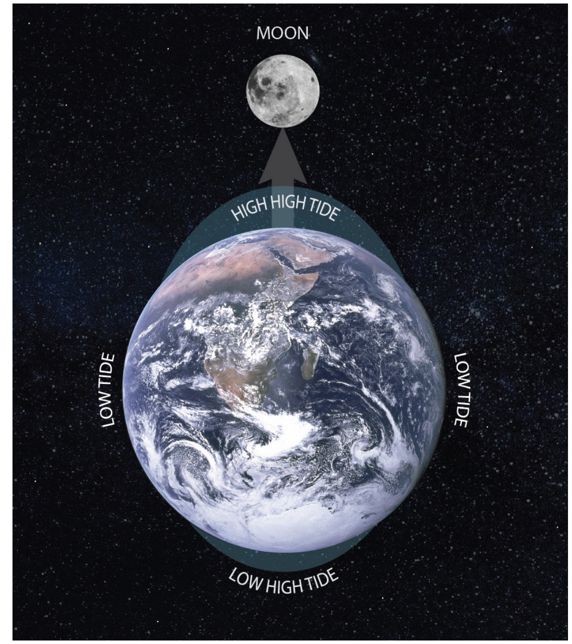
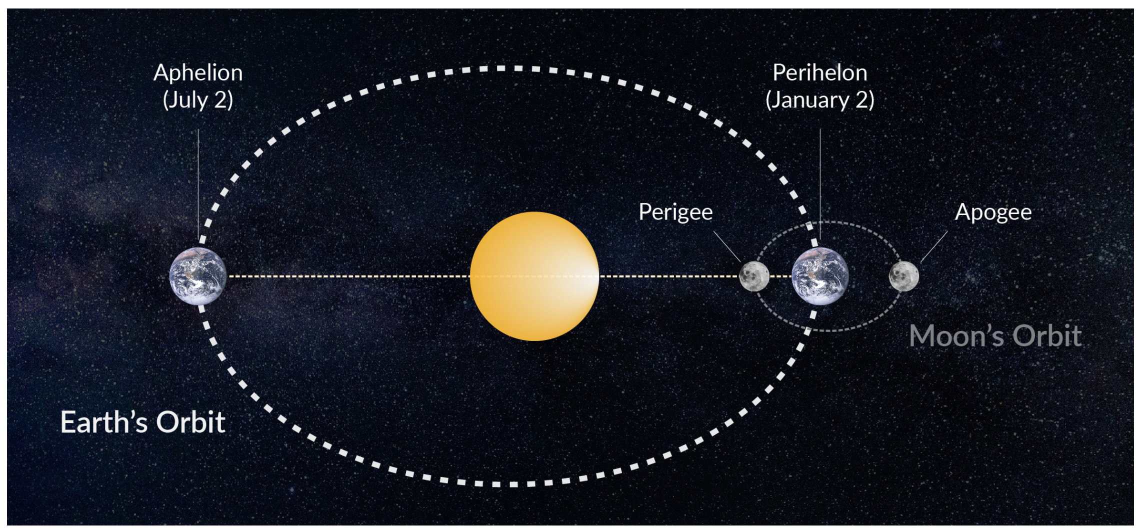


Figure 2.1-3
The orbit of the moon around the earth and the earth around the sun (based on NOAA, n.d).

Due to the elliptical shape of both orbits, once a month the moon is closer to the earth, which is referred to as the moon reaching its perigee, and once a year the earth is closest to the sun, which is referred to as the earth reaching its perihelion. These have a slight affect on tides due to the additional gravitational forces acting on the earth.



Semidiurnal Inequality (based on Pugh, 2004, p. 40)

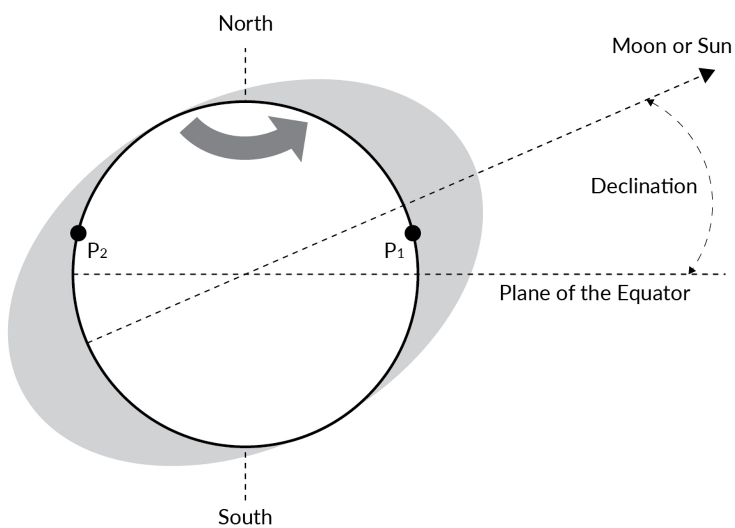


Figure 2.1-4
As the moon moves through its orbit, it passes through the plane of the equator, and the plane of the ecliptic (the earths orbit around the sun). The position of the moon and the sun in relation to the equator is referred to as declination. The declination changes through the month for the moon, and the year for the sun affect the variation in semidiurnal tides. Diurnal tides increase as declination increases (Pugh, 2004, p. 40).

The diagrams on the next page illustrates some of the lunar characteristics that influence tidal patterns.

monthly declination (distance north and south of the earth's equator) during the 18.61-year nodal cycle" (Hicks, 2006, p. 19). During this cycle, the maximum declination will range between slightly more than 18° and 28°. The declination of the sun and the moon also create diurnal inequalities in the height of the tides depending on the relationship of the moon's declination to the sun's declination.

The information above is a general approach to understanding the forces that generate tides; however, many factors contribute to the amplitude of tides. The diagrams shown on the next page show how the lunar phase, declination, and the lunar distance from the earth affect tides.

Tides contribute to flooding depending on the weather during high tides. In combination with wind setup, wave setup, storm surge among other factors, can increase the risk of floods. Most of the floods that have occurred in Vancouver have taken place in December, which also correlates with the season that experiences the most precipitation.

In Vancouver, the mixed semidiurnal tides have a range of approximately "5.1 m and a maximum elevation of 2.0 m GD" (Northwest Hydraulic Consultants, 2014, p. 17). Tides are generally larger in the winter and smaller in the summer but reach maximum elevation a few times each year and are often referred to as 'King Tides' (Ibid., p. 17). These tides are one of the most significant contributors to high water events in the Vancouver region (Ibid., p. 17).

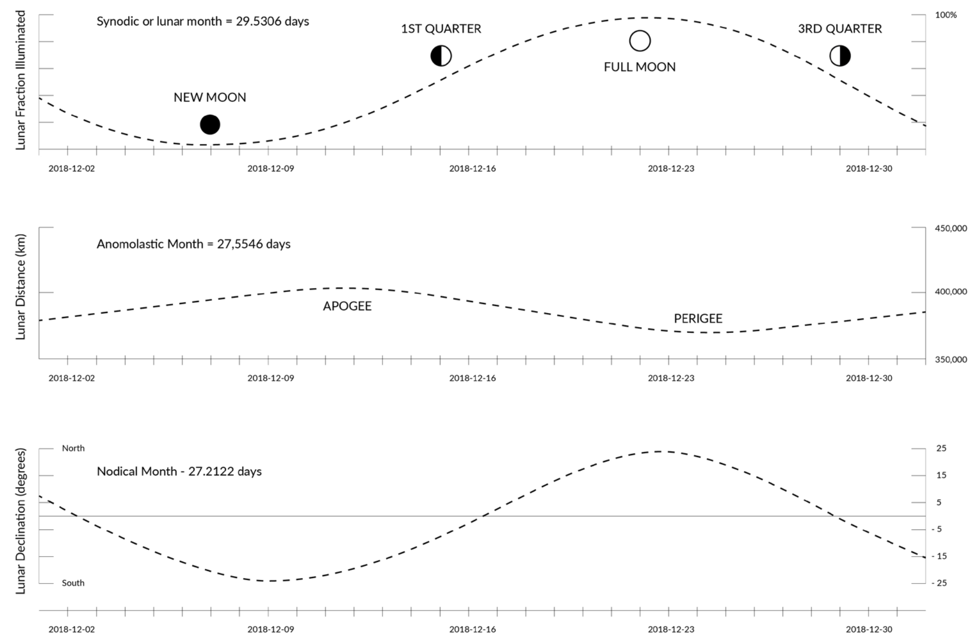


Figure 2.1-5
Lunar characteristics that influence tidal patterns (based on Pugh, 2004, p. 31).

This diagram illustrates some of the lunar characteristics that influence tidal patterns in the Vancouver tide chart diagram shown below.

The alignment of the sun and the moon during the new moon and full moon create spring tides (larger high tides). As the moon approaches perigee, this also increases the height of the tides. As the moon approaches lunar perigee the tidal range for semidiurnal tides are also reduced. Further, the greater the declination of the moon north and south of the equator influences the semidiurnal water levels, where they are higher and lower than average (Pugh, 2004, pp. 31-32).

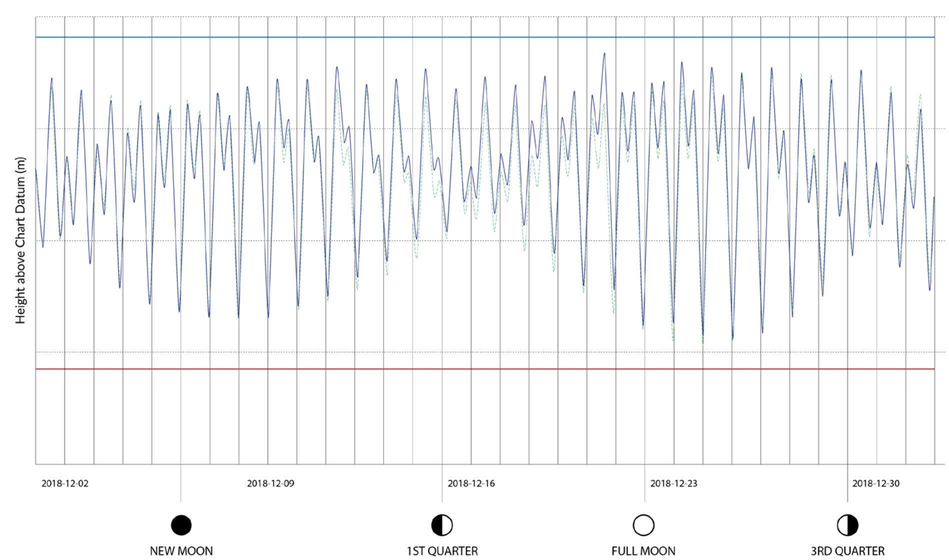


Figure 2.1-6
Observed water level tide chart diagram for Vancouver - month of December 2018 (based on Department of Fisheries and Oceans Canada, n.d.)

As seen by the two uneven high tides and two uneven low tides per day, Vancouver has a mixed semidiurnal tidal pattern. The the amplitude of the tide is influenced by a number of constituents, including lunar declination, lunar distance, and lunar phase (Pugh, 2004, p. 31).

The highest recorded tide (at the Vancouver Harbour tide gauge) reached 5.64 m chart datum. The chart datum at the Vancouver Harbour is approximately 3.045 metres below Canadian Geodetic Vertical Datum, 1928, which is the approximate mean sea level (Port of Vancouver, 2018, p. 5).

Legend

- Highest Recorded (December 1967 = 5.64)
- Lowest Recorded (December 1985 = 0.30)
- Prediction
- Observed

Inverted Barometer Effect

Atmospheric pressure has an inverse relationship with ocean levels. If the atmospheric pressure decreases, sea level will correspondingly increase, and vice versa (Pugh, 2004, p. 134). Low-pressure systems can increase sea level by 1 centimetre for each hectopascal drop in air pressure, although the barometric setup on sea levels during storms tend to range between 0.1 to 0.4 metres (Hughs, 2016, p. 7). Pugh (2004, p. 136) notes that it is difficult to distinguish the effect of atmospheric pressure from the impact of wind because the atmospheric systems that generate storms also generate winds, which also influence sea levels through wind stress.

Storm Surge and Storm Tides

Storm surge is the temporary increase in sea level due to meteorological effects, including changes to low atmospheric pressure and strong winds (Arlington Group Planning + Architecture Inc., 2013, p. 8). The term storm tide is the cumulative height of the storm surge and the astronomical tide (Pugh, 2004, p. 249). The effects of storm surge are more significant when coinciding with high tide, where coastal water and wave action may access upland areas, or overtop sea defenses, which can cause flooding, erosion, and other damage (Arlington Group Planning + Architecture Inc., 2013, p. 8).

In Vancouver, storm surge is the second largest contributor to high water events and is the result of low-pressure systems in the Pacific that make their way into the coastal waters of BC (Northwest Hydraulic Consultants, 2014, p. 17).

Figure 2.1-7
Factors contributing to flood extents (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 18).

The diagram to right illustrates the influence sea level rise, high tide, storm surge, wind setup, and wave effect have on sea levels. Taking into account a level of uncertainty, with the freeboard, suggests that land located in current flood plains will be exposed to a greater flood risk, and new upland areas will be absorbed into the flood plain.

Wind Setup

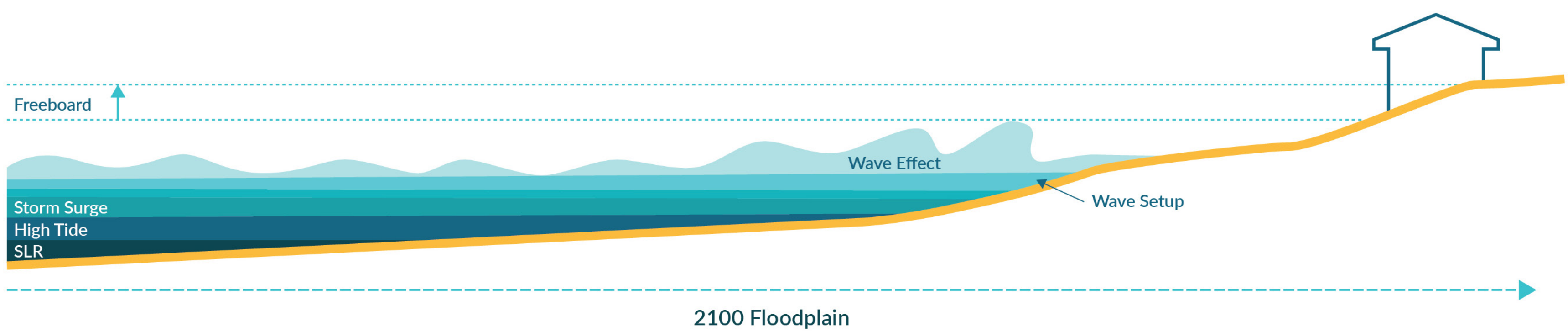
Wind setup is the result of the friction of wind movement over the surface of the water where energy and momentum of the wind are transferred to the water, causing it to pile up towards the shore (Pugh, 2004, p. 138). The effect of wind setup also has an inverse relationship with the depth of water, causing it to be more elevated in shallower water (Ibid., p. 139). The time scale that this occurs affects the direction of the wave to the wind due to the Coriolis effect. In the northern hemisphere, the movement of water will deflect to the right of the direction of the wind, whereas in the southern hemisphere it will deflect to the left (Pugh, 2004, pp. 138 - 139; Hicks, 2006, p. 32).

In Vancouver, wind setup is the fourth most significant contributor to high water levels; however, False Creek is the only area significantly prone to wind setup (Northwest Hydraulic Consultants, 2014, p. 17).

Wave Setup and Wave Runup

Wave setup is an increase in water level due to the momentum transfer from the breaking of, or dissipation of wave energy, to the water column in the shoreward direction (Hughs, 2016, p. 5). The balancing of the momentum of energy results in a slope of water upwards on the coast that is higher than the water level when there are no waves (Ibid., p. 5). Wave runup is the extent the wave moves up the slope of the coast.

In the Vancouver region, waves are generated locally due to the semi-enclosure of the Strait of Georgia (Northwest Hydraulic Consultants, 2014, p. 17). Large waves can generate from strong winds moving along the axis of the basin and expose areas west of the First Narrows (near Stanley Park and English Bay) to wave setup and runup (Ibid., p. 17). In Vancouver, wave setup is the third largest contributor to high water level events (Ibid., p. 17).



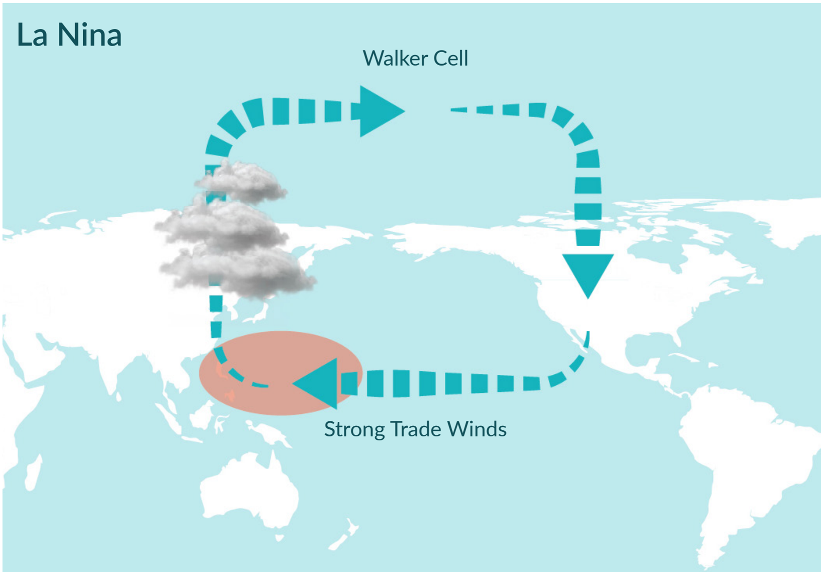
Pacific Decadal Oscillation and El Nino Southern Oscillation Climate Variations

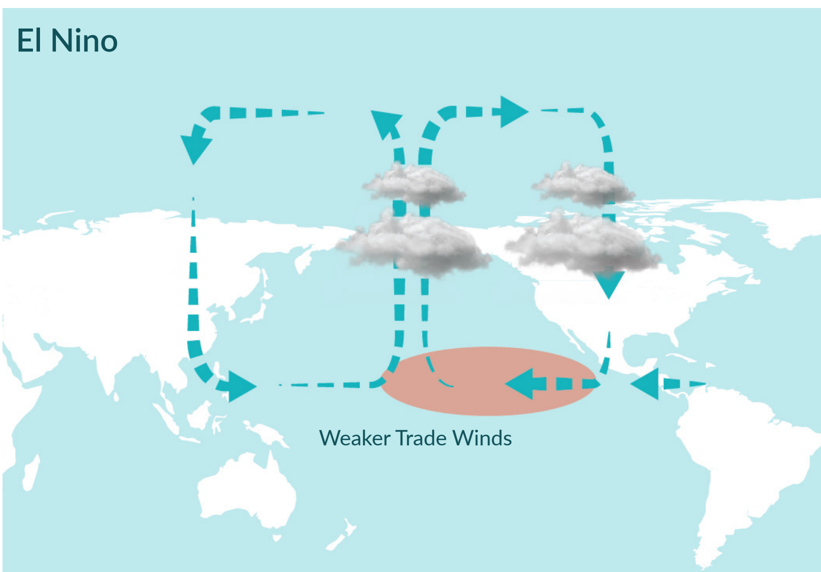
Pacific Decadal Oscillation (PDO) and El Nino Southern Oscillation (ENSO) are climate variations due to sea temperature shifts in the Pacific Ocean. The PDO and ENSO vary over different timescales, with PDO alternating phases that can last as long as 20 to 30 years and ENSO cycles lasting between 6 to 18 months (North Carolina Climate Office, n.d.). Sea surface temperatures help identify the oscillation changes between a warm El Nino phase, where sea temperatures are higher than average, and a cooling La Nina phase, where sea temperatures are lower than average. The Walker Cell that occurs over the Pacific Ocean helps provide an understanding of the ENSO events. The Walker Cell occurs over the Pacific Ocean, which is generated by the trade winds moving east along the equator in the Pacific Ocean (from a high-pressure system to a low-pressure system) (James and Stull, 2019). As the warm air temperatures approach the western Pacific coast the warm water evaporates, through which during this process, warm air loses moisture through precipitation and can cause intense storms and flooding in areas along the Pacific west coast (Australian Government Bureau of Meteorology, n.d.). As the air continues to rise it hits the tropopause which forces it to move laterally, and within this convection, cold air moves east and descends to the high-pressure system on the eastern Pacific coast (Snodgrass, 2011).

During a warm El Nino phase, trade winds along the equator weaken and the warm water in the western Pacific shifts back towards the eastern Pacific coast. The weakening of the trade winds also shifts the Walker Cell towards the eastern Pacific coast, bringing more rain and warmer temperatures further east, as well as higher ocean levels associated with the thermal expansion of the warmer ocean waters (NASA, 2015).

During a cooler La Nina event, the movement of air is similar to the neutral phase, but the trade winds moving west along the equator in the Pacific Ocean are intensified and more warm water piles up along the western Pacific coast, bring warmer temperatures and rain to this coast. This process also results in cooler temperatures to the eastern Pacific coast as well as cool ocean temperatures due to the upwelling of deep, cold ocean water (Australian Government Bureau of Meteorology, n.d.). The upwelling of the nutrient-rich cooler water also helps marine ecosystems, such as salmon habitats where the additional nutrients help facilitate the growth of plankton, which support the survival of juvenile salmon (NOAA, 2017). The upwelling of colder water also occurs during the cool phase of a Pacific Decadal Oscillation.

The warm phase of a Pacific Decadal Oscillation brings similar conditions that El Nino brings, and results from a horseshoe-shaped pooling of a warm body of water on the eastern Pacific coast. The cooling phase of a Pacific Decadal Oscillation brings similar conditions as a La Nina event, and trap cooler water and temperatures on the eastern Pacific coast. Although the cause of the PDO is still unknown, it is believed it can “intensify or diminish the impacts of ENSO according to its phase” (North Carolina Climate Office, n.d.).





Both the PDO and the ENSO can impact ocean levels due to expansion and contraction of water in response to the temperature of the ocean. Further, increased storms due to the warm phases of these events can increase wave energy and storm surge on the coast, which can increase flooding and erosion along coastlines (Barnard et al., 2015). Reports also indicate that PDO and ENSO events can "influence water levels as much as 40 cm" (Northwest Hydraulic Consultants, 2014, p. 17).

Since 1960, there have been many ENSO cycles and only two PDO cycles; however, because these variations occur over longer time scales, the practical application of these variations in modelling are "often lumped in with storm surge" (Ibid., p. 17).

Figure 2.1-8 (Top)
Walker Cell and La Nina (based on James and Stull, 2019).

During the cooling phase of La Nina, trade winds strengthen across the Pacific Ocean moving warmer waters to pile up in near the wester Pacific Coast, bringing intense storms to this side of the ocean.

Figure 2.1-9 (Bottom)
Walker Cell and El Nino (based on James and Stull, 2019).

During the warming phase of El Nino, the trade winds weaken in the Walker Cell, causing warmer waters to shift back towards the eastern Pacific Coast. Due to thermal expansion, sea levels increase where the warm body of water is present.

Sea Level Rise

There is still uncertainty on the rate of sea level rise that will occur (Northwest Hydraulic Consultants, 2014, p. 11) over the next hundred years and the impacts it will have. This uncertainty is from a number of factors, including the rate of the increase in ocean temperatures and thermal expansion, timing for when the ice shelf in the Antarctic collapses, and the rate of isostatic rebound or land subsidence. The sea level rise policy for British Columbia projects that sea level will rise by one metre by the year 2100, and as much as two metres by the year 2200. However, the projection reflects a degree of uncertainty by illustrating that by 2100 the sea level rise range could extend from 0.5 metres to 1.3 metres, and by 2200 the range could extend from 1.4 metres to 3.4 metres (Ibid., p. 11). Taking into account the one metre of sea level rise by 2100 may be a conservative projection suggests that the policy intends to prompt action and provide time for jurisdictions to prepare for sea level rise.

In the Phase 1 Coastal Flood Risk Assessment Report, consultants considered five scenarios to identify the potential hazards and flood risks for Vancouver. These scenarios not only consider the provincial policy curve, but they also consider sea level projections by Natural Resources Canada, which indicate a 30 to 50 cm sea level rise by 2100 for Vancouver (Ibid., p. 14). The Phase 1 report identifies that using the Natural Resources Canada projection, in combination with an estimated sea level rise of 30 to 60 cm from the "potential collapse of the West Antarctic ice sheet, result[s] in an overall range between 0.6 m to 1.1m" (Ibid., p. 14).

Another major factor in determining the flood risk is the return period of a high water event. The Phase 1 report identifies that a return period is "a measure of the average length of time in years for an event of a given magnitude to be equaled or exceeded, independent of [sea level rise]" (Ibid., p. 14). The report indicates that a 500 year and 10,000 return period were selected due to recommendation of the technical advisory committee and that using a 1:10,000 return period is common practice in various regions throughout the world, including the Netherlands; and that the 1:500 return period is a standard in the BC provincial floodplain mapping guidelines (Ibid., p. 14). Over the time frame of 100 years, the probability for a 500-year return period is 18% (Ibid., p. 14).

Through the analysis of the Phase 1 work, Scenario 3 was chosen by the City of Vancouver, in consultation with their technical advisory committee, to inform future policy decisions (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 18). Scenario 3 considers the "effects of sea level rise (SLR), high tide, storm surge, and wind set-up, wave set-up, wave effect, and 0.6 m freeboard. Each of these components of flood level that determine extent estimates;" however, this scenario does not take into consideration climate change that may affect the intensity and frequency of storms (Ibid., p. 18).

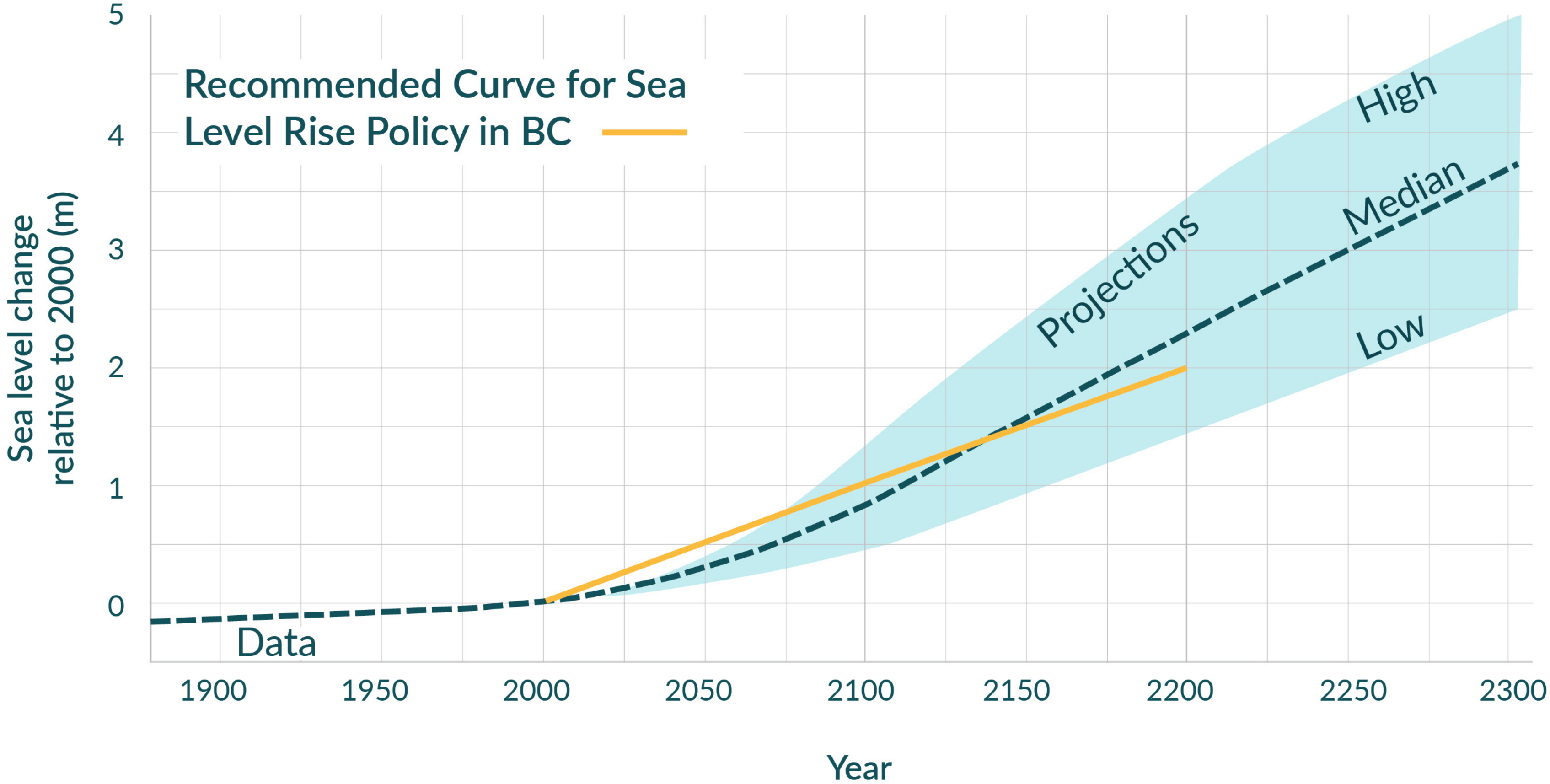


Figure 2.1-10
Sea level rise policy curve for British Columbia (based on Ausenco Sandwell, 2011a, p. 2).

The sea level rise curve illustrated in the diagram above indicates uncertainty in the projection of sea level rise over the next 300 years. Although ahead of data projections, the policy curve provides a benchmark for coastal jurisdictions to inform policy decisions to adapt to the changes that will be brought by sea level rise.

Flooding Hazards and Vulnerabilities

The Phase 1 analysis identified a number of impacts to people and infrastructure anticipated to increase as sea level continues to rise. The Phase 2 report (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 9) notes that it is expected that there will be significant impacts to the built environment and people during coastal flood events, which will continue to increase. With an increase in one metre of sea level rise, it is projected that up to 4000 households would be displaced and water would damage approximately 800 buildings citywide with a 1:500 event (Ibid., p. 9).

The report also notes that hazards would generate almost 4,500 dump trucks of debris, disrupt major transportation routes and impact infrastructure, facilities, and cultural sites along the coastal edges of the city (Ibid., p. 9). These impacts would have a ripple effect, such as indirect economic losses, environmental and social impacts. Flooded buildings and streets can disrupt businesses or immobilize transportation and goods routes (Ibid., p. 9). Water can become contaminated if exposed to pollutants, and the coast can face damage due to waves or other water-related damage, both of which can also affect habitats along the coast. People affected by flooding can be displaced and traumatized (Ibid., p. 9).

Flood Construction Levels

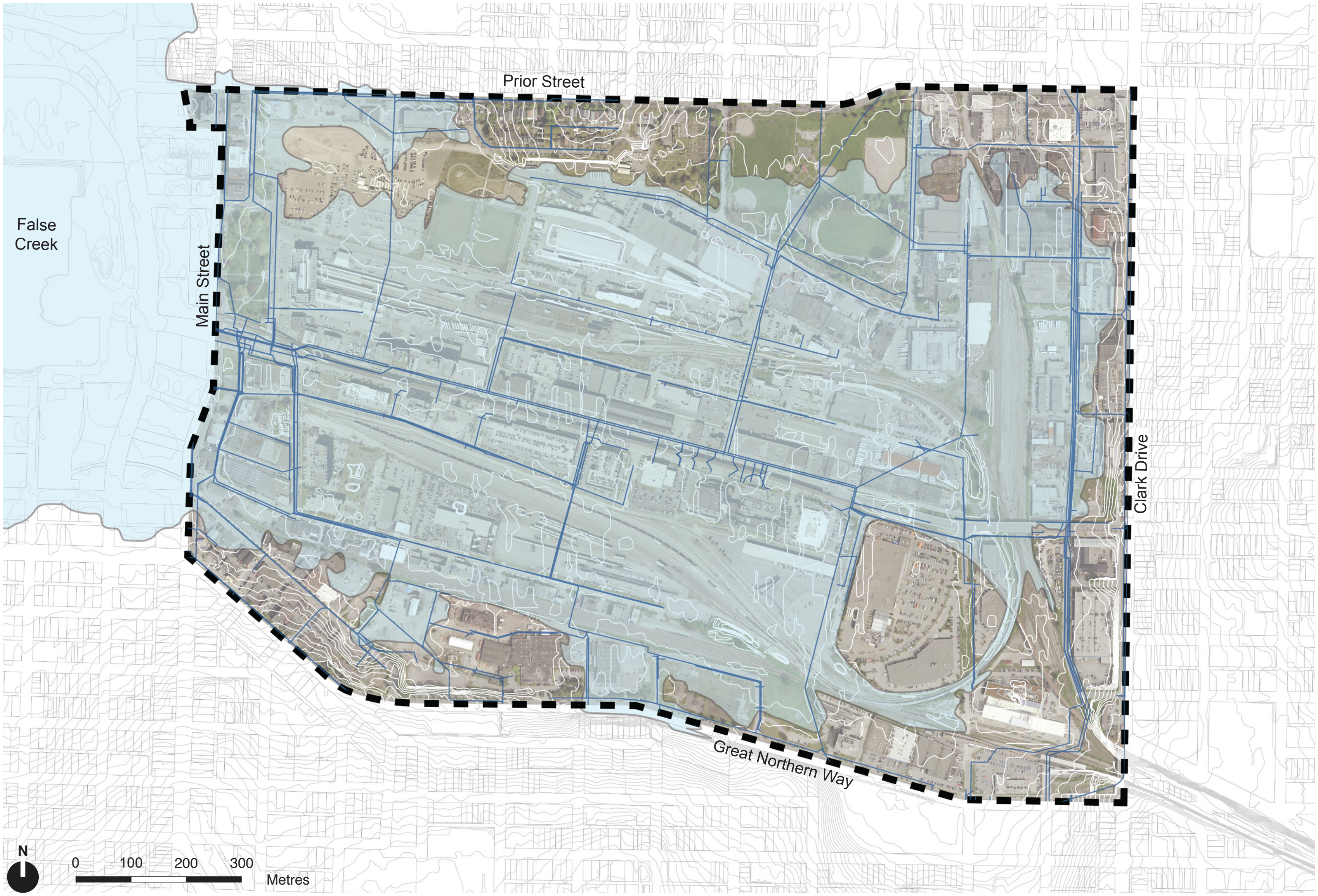
The current Flood Construction Level (FCL) for False Creek Flats, implemented in 2015 (Northwest Hydraulic Consultants, 2014, p. iv), is set at a 4.6 m GD (geodetic datum), an increase from the previous 3.5 m GD FCL. The current FCL is based on the Phase 1 analysis and incorporates a 1 metre rise in sea level, a 500-year return period, and a 0.6 metre freeboard to address uncertainty in the FCL calculations, providing an additional measure of safety in floodplain areas (Ibid., pp. iii, 69-70). In areas exposed to wave effect an additional 0.3 metres is added to the FCL (Ibid., p. 69); however, False Creek Flats is located shoreward of this boundary and therefore is not subject to this additional height.

Figure 2.1-11 (Right)
Storm sewers network and floodplain zone

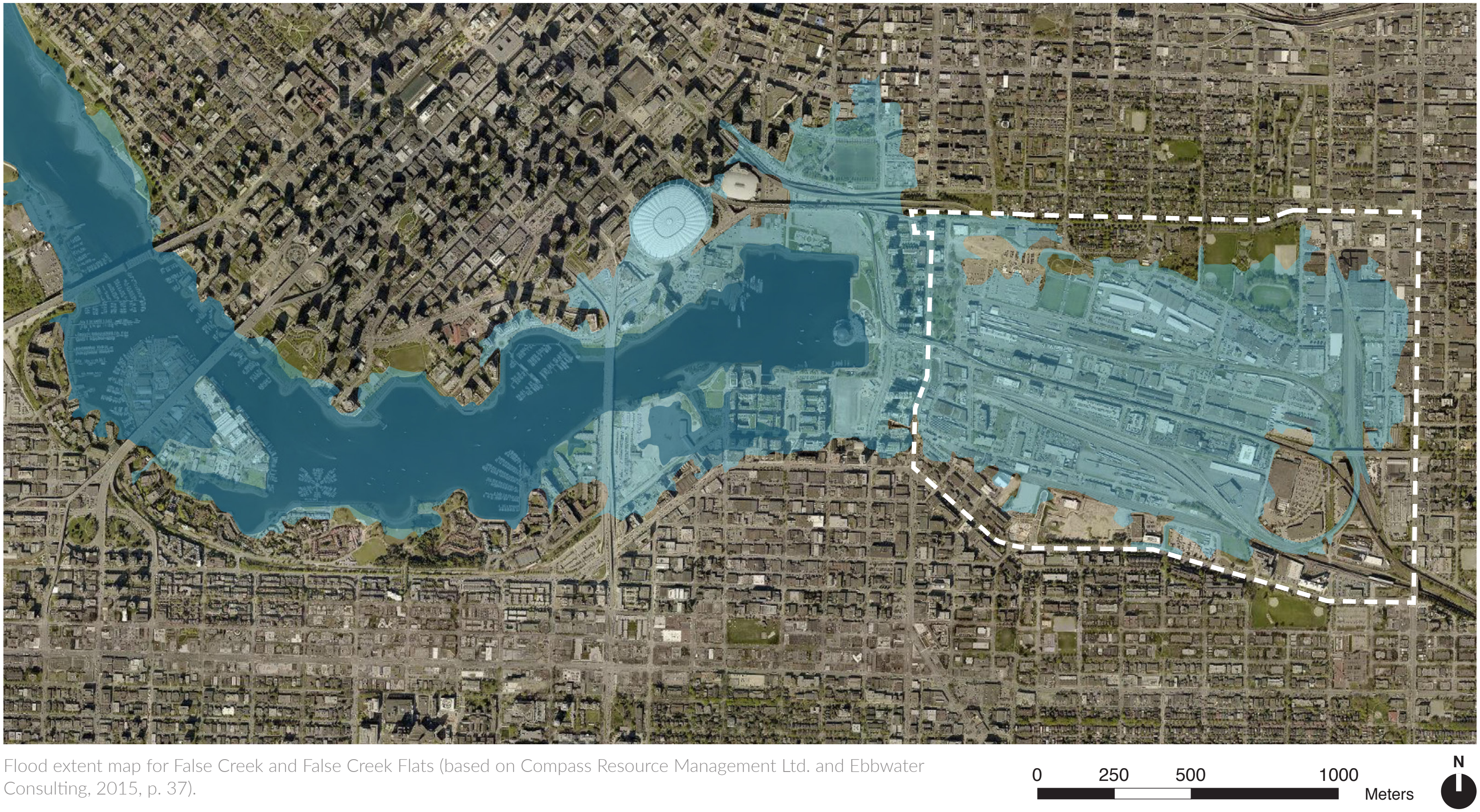
The diagram to right illustrates the floodplain extent in the False Creek Flats, combined with the storm sewer network.

Being so close to the waterfront, most of the False Creeks Flats is within the floodplain zone, which includes land within 4.6 metres GD Flood Construction Level.

Storm Sewers Network and Floodplain Zone



Flood Extent Map of False Creek and False Creek Flats



Flood extent map for False Creek and False Creek Flats (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 37).

Figure 2.1-12
The above map indicates the potential flood extents for False Creek and False Creek Flats with two scenarios.

The dark blue indicates a 0.2% flood at current conditions (no change in sea level rise), or a high tide in the year 2100, with a one metre rise in sea level. The light blue areas indicate a 0.2% flood event in the year 2100 with a 1 metre rise in sea level (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 37).

As shown in the map, a 1 metre rise in sea level rise will have a significant impact on the False Creek shoreline and a substantial area in the False Creek Flats, with extents almost reaching Clark Drive.

Flood Risk and Stormwater System Capacity

Figure 2.1-13
In the Phase 1 Coastal Flood Risk Assessment, an analysis was done to determine how sea level rise will impact storm sewer systems. However, prior to this modeling, a high level analysis was conducted to determine the current capacity of the storm system based on a 25 year rainfall event (Northwest Hydraulic Consultants, 2014, p. 83). In a simulation model of the existing conditions, many nodes throughout the False Creek Flats suggest the system is near capacity independent of sea level rise considerations, as many nodes indicated minor flooding (depths less than 0.11 m) (Ibid., p. 83).

Modeling the sea level rise scenario with a 1 metre rise in sea level by the year 2100, and a 500 year event (not including freeboard) (Ibid., p. 85), it is clear the storm system will be impacted by sea level rise and will not be able to discharge flows to False Creek. This model assumed that peak rainfall and maximum sea level are occurring coincidentally, and that precipitation amounts are not affected by climate change (Ibid., pp. 85-86).

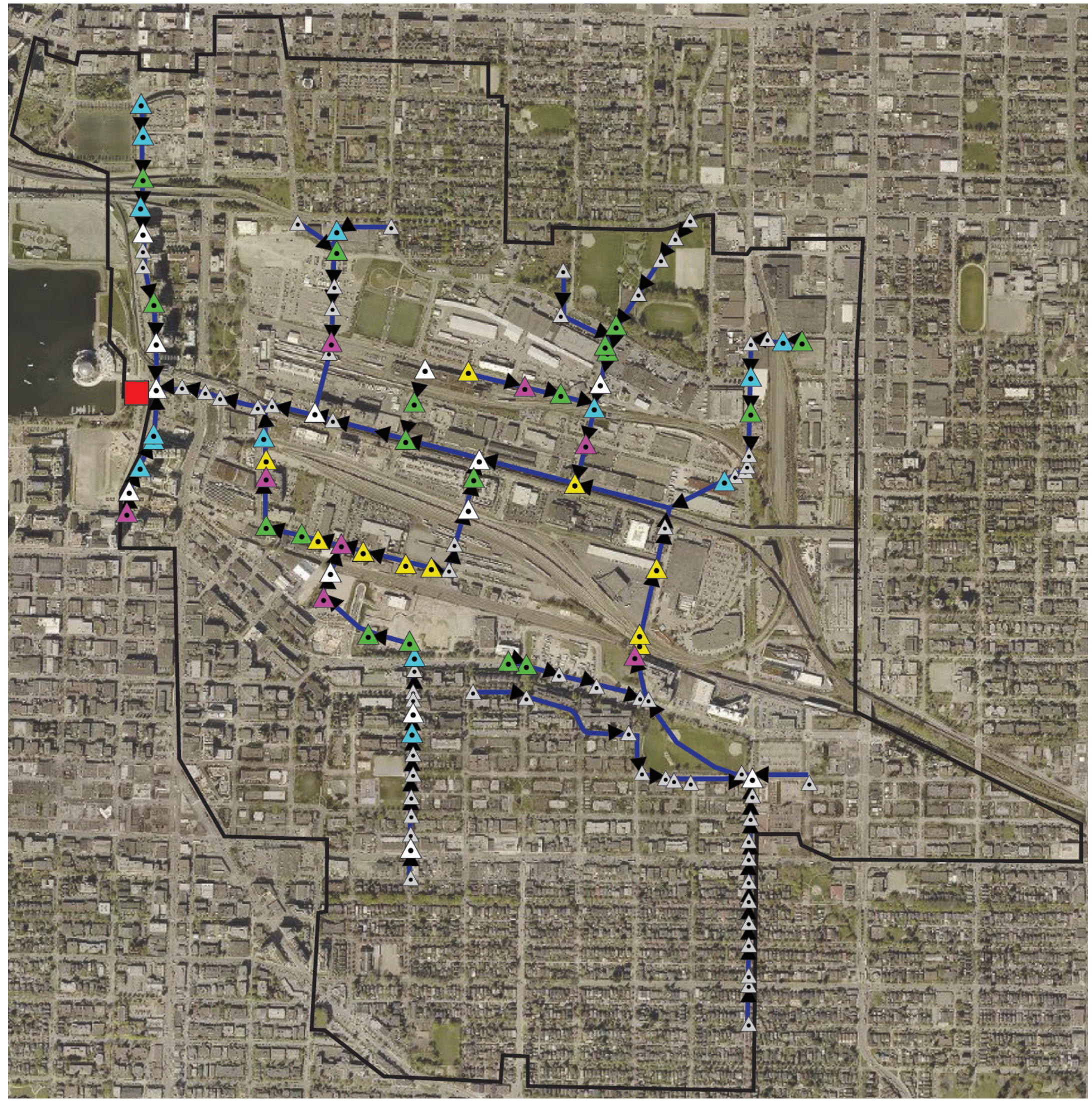
The report also notes that peak tidal stages are at elevations 3 metres or higher in the sea level rise scenarios, and are too high to allow gravity discharges without concurrent street flooding due to backwater levels (Ibid., p. 93). To remove the risk of street flooding, the Phase 1 Coastal Flood Risk Assessment report suggests adding at pump station at Quebec Street and Terminal Avenue to pump stormwater over a flood wall into False Creek (Ibid., p. 92).

Legend

- False Creek Outfall
- Conduits
- Basin

Nodes Flooding > 5 minutes
Flood Depth (metres)

- Less than 0.11
- 0.11 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 1.25



Flooding depths for Scenario 3 with a 25-year design storm (based on Northwest Hydraulic Consultants, 2014, p. 91).

0 125 250 500 Meters

N

2.2 Flood Protection Options and Evaluation

Flood Protection Options

The Phase 2 Coastal Flood Risk Assessment report (Compass Resource Management Ltd. and Ebbwater Consulting, 2015) looked at four options to provide flood protection to False Creek and the False Creek Flats. These options incorporated measures to protect or adapt; however, these options did not include the possibility of retreat due to the "future value and strategic importance of this area" (Ibid., p. 38).

Of the four options shown in the report (Ibid., p. 38) three include 'protect' approaches, and one includes an 'adapt' approach:

1. Sea Barrier at Burrard Bridge
2. Raised Seawall along False Creek
3. Partial Dike at Quebec Street
4. Adapt using multiple tools

The first three options are visualized on the following pages and include a summary of the high-level approaches to provide flood protection from sea level rise for False Creek and the False Creek Flats. Following these summaries is a table that summarizes the consequences of each option and effectiveness in mitigating the associated flood risk impacts.

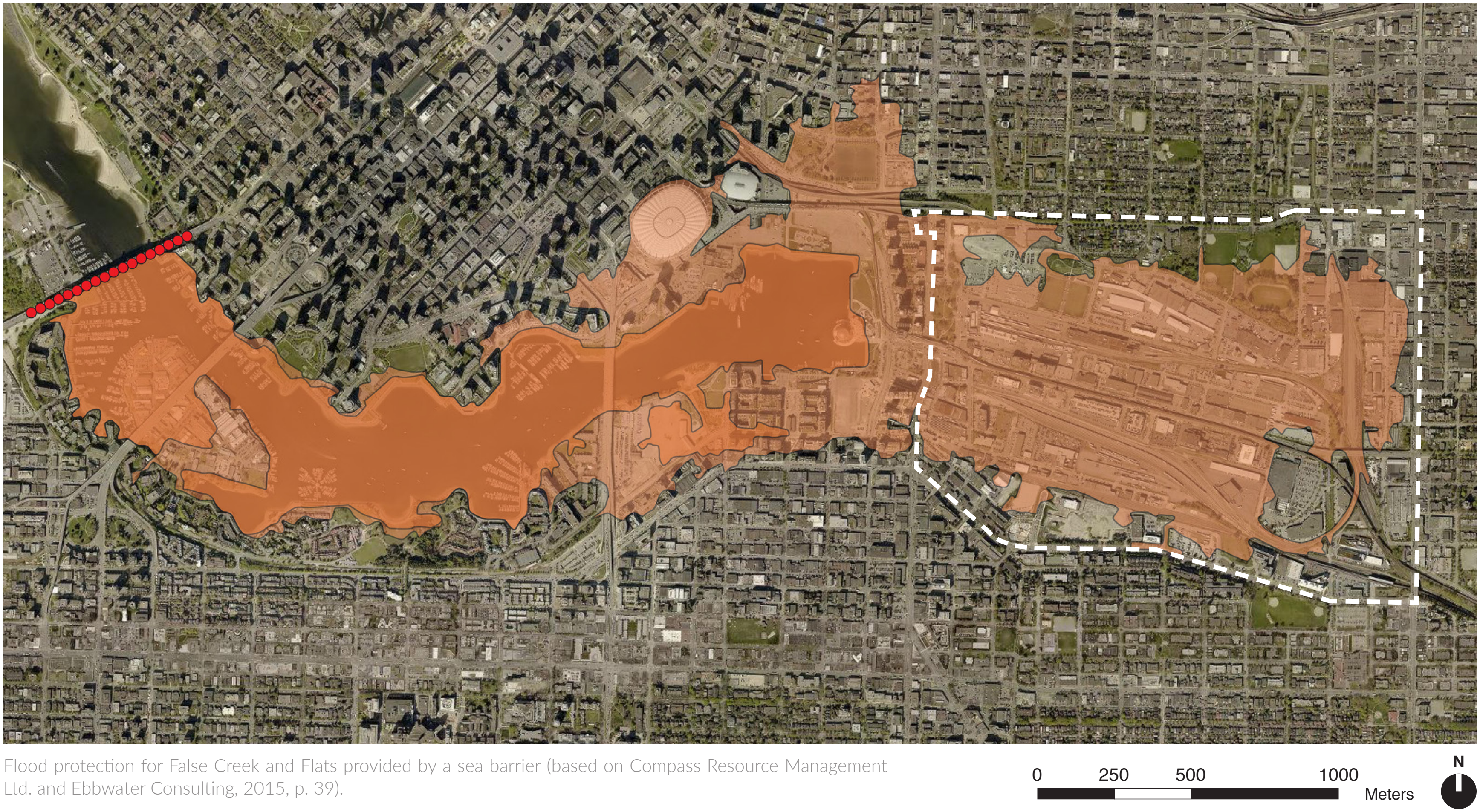
The 'adapt' option is based on the approach that coastal communities can absorb some inundation through a process of retrofitting existing buildings and infrastructure, so they are resilient to flooding. Also acknowledged is that this option can include a number of approaches, including "educational, "planning, and building options" (Ibid., p. 42).

More specific options considered in the assessment for the 'adapt' approach include:

- Bylaws to prohibit critical infrastructure in the floodplain;
- Elevating infrastructure services, such as utilities and roads;
- Amending the building code, and developing incentives to help property for owners implement flood protection measures;
- Education for specific flood proofing approaches for property owners; and
- Continued development for a flood warning system to allow people to get out of harm's way during a high ocean event (Ibid., p. 42).

This approach provides multiple ways to address flood risk and the report identifies that it can be implemented quickly and while also slowly helping provide flood resilience over time (Ibid., p. 42).

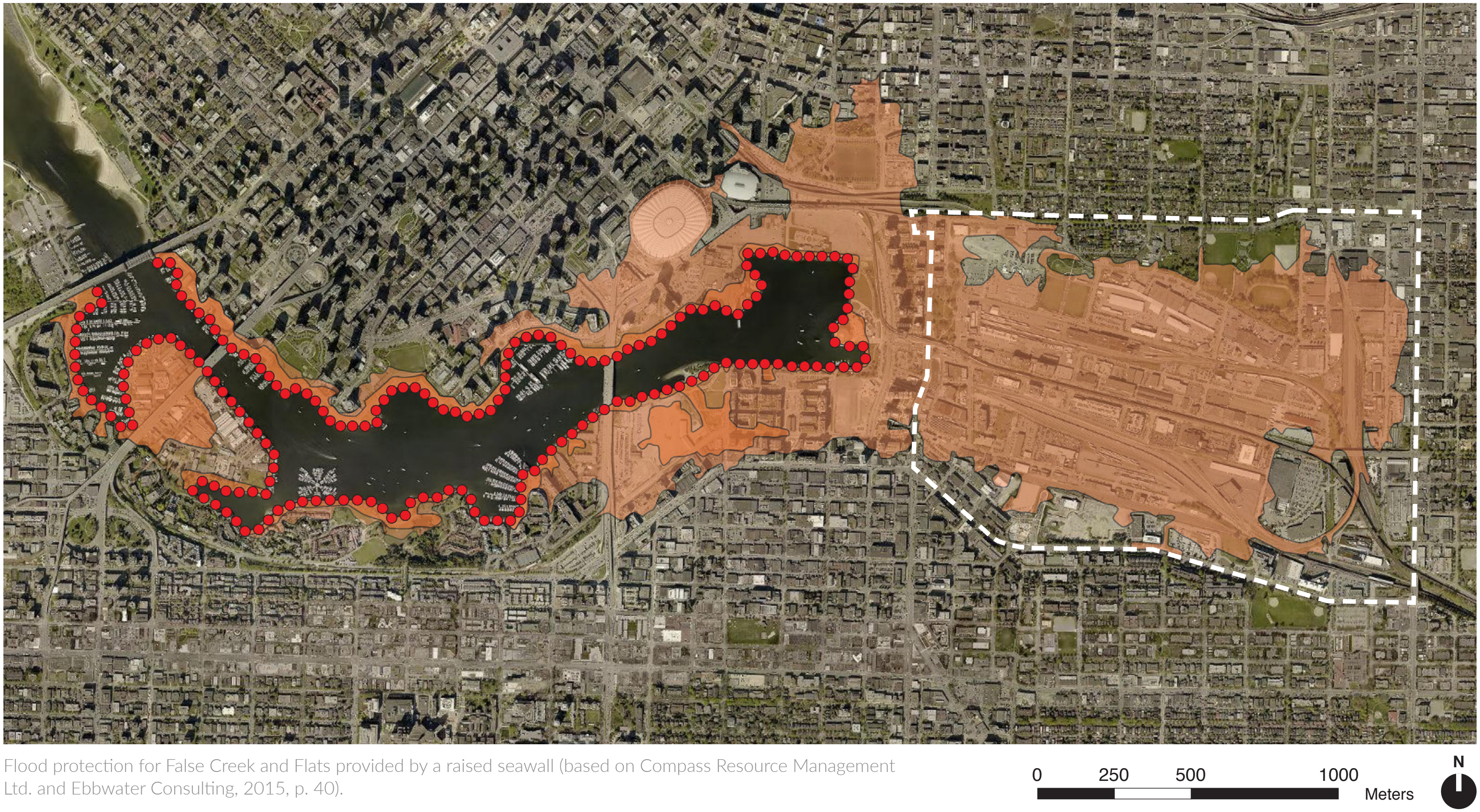
‘Protect’ Option 1 - Flood protection provided by a sea barrier at the Burrard Bridge



Flood protection for False Creek and Flats provided by a sea barrier (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 39).

Figure 2.2-1
The red dots in the map above shows the approximate location at the Burrard Bridge, where a sea barrier could be used to eliminate the flood risk in the areas highlighted in orange. The False Creek Flats area is located within the dashed white line boundary. The Phase 2 Coastal Flood Risk Assessment report (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 39) indicates that for the most part the flood gate would be open, and intermittently closed during events that could cause flooding such as storm surge and high-tide. The report also notes that for False Creek, a sea barrier would need to be at least 10 m tall and 360 metres wide, and that the sea barrier would be effective in mitigating current flood risks and be in operation as many as four times a year to reduce flooding at Granville Island, Hinge Park (near Olympic Village), and portions of the current seawall with lower elevations (Ibid., p. 39).

‘Protect’ Option 2 - Flood protection provided by a raised seawall along False Creek



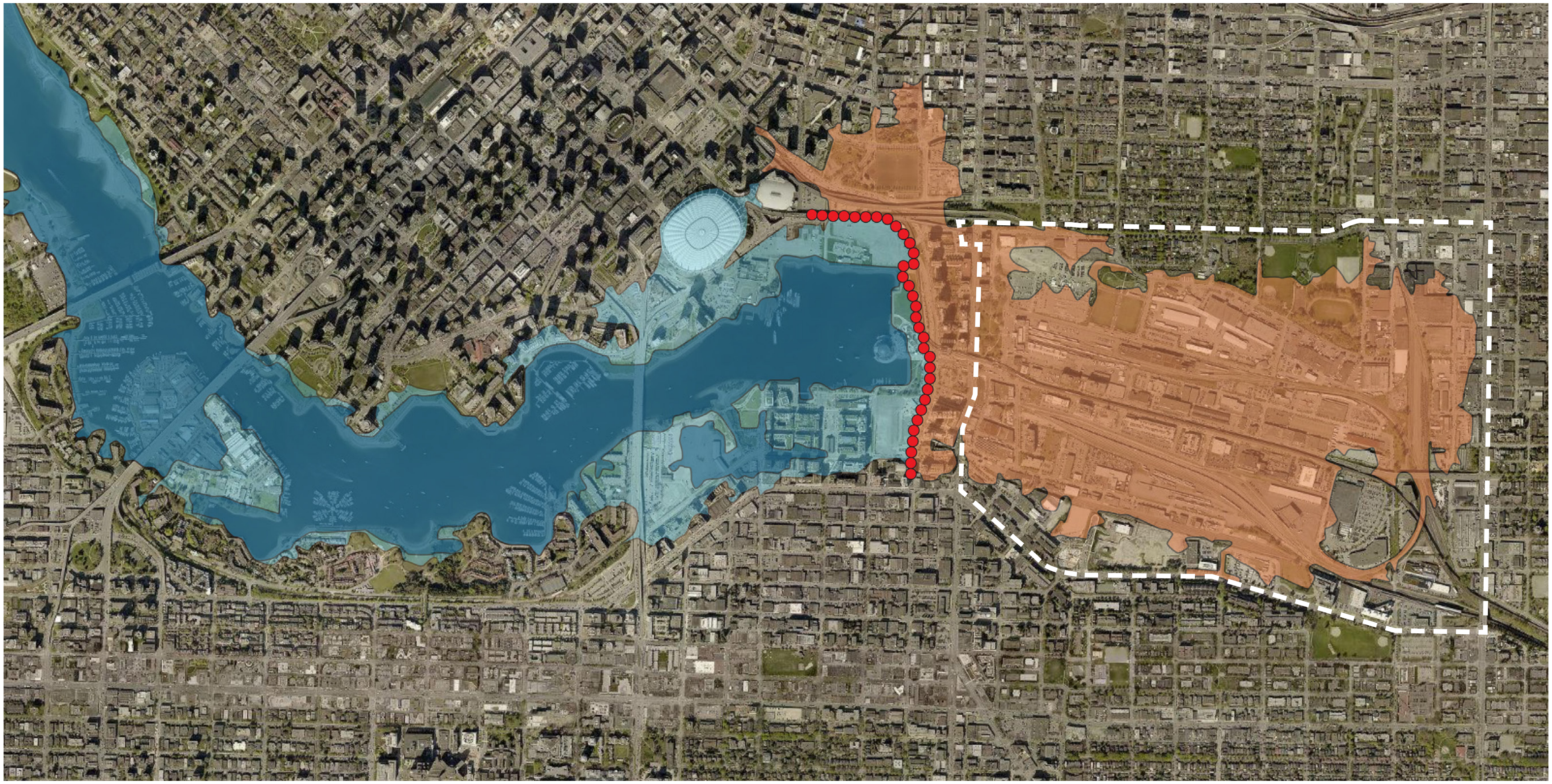
Flood protection for False Creek and Flats provided by a raised seawall (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 40).

Figure 2.2-2

The red dots in the map above shows areas along the False Creek shoreline that would require the seawall to be raised to the 4.6 metre geodetic flood construction level east of the Burrard Bridge to provide protection to the areas highlighted in orange. The False Creek Flats area is located within the dashed white line boundary.

This shoreline encompasses 8.6 km of seawall, most of which would need to be raised 2.3 metres above grade, whereas some low lying areas may require the wall to be elevated as much as 6.3 metres (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 40). The Coastal Flood Risk Assessment report (Ibid., p. 40) identifies that although some portions along the wall could integrate in to adjacent public space, other areas will likely require more extensive engineering to integrate into existing structures or buildings. As visualized above this approach would also protect False Creek Flats from overland flooding.

‘Protect’ Option 3 - Flood protection provided by a partial dike at Quebec Street



Flood protection provided by a partial dike with alignment near Quebec Street (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 41).

Figure 2.2-3
The red dots in the map above shows the area along Quebec Street that would require the construction of a partial dike and the areas, highlighted in orange, provided flood protection by this measure, and the areas, highlighted in blue, west of the dike that would not be protected. The False Creek Flats area is located within the dashed white line boundary. This option would also require sidewalks and bicycle lanes on the west of Quebec Street between Pacific Boulevard and E 1st Avenue to be elevated (Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 41).

Analysis of Flood Protection Options for False Creek

The table on the next page suggests that the options that provide the greatest flood protection include the sea barrier at the Burrard Bridge, and the raised seawall along False Creek. These options come at a significant cost, with the sea barrier costing almost $850 million, and the sea wall costs reaching almost $300 million. The least expensive option includes the partial dike at Quebec Street; however, it is unclear what the costs this would incur to False Creek, which would not be protected. Surprisingly, the option that considers an adaptive approach is considered to be the least effective in providing flood protection to False Creek and the False Creek Flats. Due to the number of variables suggested would be incorporated into this approach, such as amending codes and bylaws, this option is not as clearly illustrated as the others.

Considering the coastal flood risk assessment reports are providing high level options to address the impacts of sea level rise, it is unfortunate that different approaches to make False Creek and False Creek Flats adaptive to sea level rise have not been explored in as much detail as the 'protect' approaches.

Table 2-2-1 (Right)
The table to right is included as part of the analysis provided in the Phase 2 Coastal Flood Risk Assessment report (Compass Resource Management Ltd. and Ebbwater Consulting, 2015). As indicated in the table, the option that provides the greatest protection is the addition of a sea barrier at the Burrard Bridge location, at a potential cost of $850 million. The analysis also determined that adaptive options would be least effective in mitigating flood risks.

Flood protection (per event)	Baseline	Sea Barrier	Raised Seawall	Partial Dike	Adapt
Impacts of a 0.2% flood event in Economic 2100	$76M in damages $76M in lost inventory $3M in emergency response	Full protection	Full protection	100% of baseline losses	70% of baseline losses
Social	4000 people displaced	Full protection	Full protection	95% of baseline	70% of baseline
Parks	0.3 km^2	Full protection	Full protection	50% of baseline	As baseline
Sites with possible contaminants	No protection	Full protection	Full protection	Partial protection	Sites would need to be cleaned
Impacts of King Tides and common flood events	Gradual periodic inundation of low-lying areas, accelerating after 2050-2070	Full protection	Full protection	Full Protection of Flats No protection for other areas	
Implications of the Management Action (or Inaction)					
Direct implementation costs	None	$500-$850 M	$200-$300 M	$10M	$338M
People permanently displaced	>1000 people forced out by SLR	Full protection	Full protection	>1000 people forced out by SLR	>250 people forced out by SLR
Loss of land opportunity by 2100	2.6 km^2	None	None	0.9 km^2	N/A
Aesthetics	None	Likely negative relative to today	Likely negative relative to today	Likely negative relative to today	Possibly low impact
Environmental	None	Potential to impede water movement	None	None	None
Adaptability (Ability to change direction later)	High	Low	Potential to implement in stages	Potential to implement in stages	Potential to implement in stages

Summary consequence table for False Creek and False Creek Flats (based on Compass Resource Management Ltd. and Ebbwater Consulting, 2015, p. 44)

Chapter 3
Coastal Resilience

3.1 Coastal Resilience for False Creek Flats

- Resilience
- Strategies for Sea Level Rise

3.2 Robust Approach

- Retreat Case Study - Blue Acres Buyout
- Protect Case Study - Corktown Common

3.3 Adapt Approach

- Adapt Case Study - HafenCity, Hamburg
- Green Infrastructure
- Low Impact Development
- Living Shorelines
- Coastal Wetlands

3.4 Transformative Approach

- Aesthetic Performance
- Legibility and Image of the City

Figure 3.0-1
Waves at Sunset Beach, Vancouver

3.1 Coastal Resilience for False Creek Flats

Resilience

Resilience is a term often used when people consider how cities will respond to climate change. In consideration of flood risk, Restemeyer et al. (2015, p. 46) identify resilience as a risk management approach, one that does not prevent the risk from occurring but adapts land-use to lessen the potential of damage. To operationalize resilience, Restemeyer et al. (2015, p. 47) propose a strategy-based framework to gauge resilience within a spectrum of being robust, adaptable, and transformative in relation to content, context, and process. In the context of flood risk, robustness is characterized as a city being able to defend against a flood event; adaptability is when the city can accommodate a flood event; transformability is about shifting people's relationship with water and one where it is part of people's lives rather than working to keep it out (Ibid., p. 47). To achieve the varying degrees of resiliency, content includes the methods to reduce flood risk; context considers the reasons for why a specific strategy was chosen, as well as the legislative structure and how responsibility is divided among public and private stakeholders; and process considers human capacity as it relates to intellectual, social, and political capital among public and private stakeholders (Ibid., pp. 47 - 48).

This framework is particularly relevant for the False Creek Flats and other flood-prone areas within the City of Vancouver. In strategizing how the city will address coastal flood risk due to global warming and sea level rise, the City of Vancouver is working to identify strategies to adapt to sea level rise and climate change, with policies and plans including the Greenest City Action Plan (City of Vancouver, 2015), the Integrated Rainwater Management Plan (City of Vancouver, 2016), and the Coastal Flood Risk Assessment reports (Northwest Hydraulic Consultants, 2014; Compass Resource Management Ltd. and Ebbwater Consulting, 2015). However, part of this work will also need to consider changes to the city's approach to managing sea level rise, making room for the water and shifting the cultural mindset of how development occurs and what it means to live within a dynamic coastal system.

Currently as one walks along the waterfront of False Creek, there are hints to how public space is designed to accommodate varying levels of water whether it is reflected in the raised terraces of the seawall, giant stepping stones to reach high tide islands, or even the visibly wet concrete or rip-rap along the water's edge showing the extent of the most recent high tide. It is much less visible in False Creek Flats where the historic tidal flat and the streams that fed it have been filled in. This disconnect with the landscape/waterscape can inhibit people's perception of risk in living next to the water. It can also reduce the perceived value of the water's edge and what is needed to sustain it and the land it protects. Making people more aware of how the landscape fits within the larger system can help build capacity to take action or support decisions that will make the city more flood resilient.

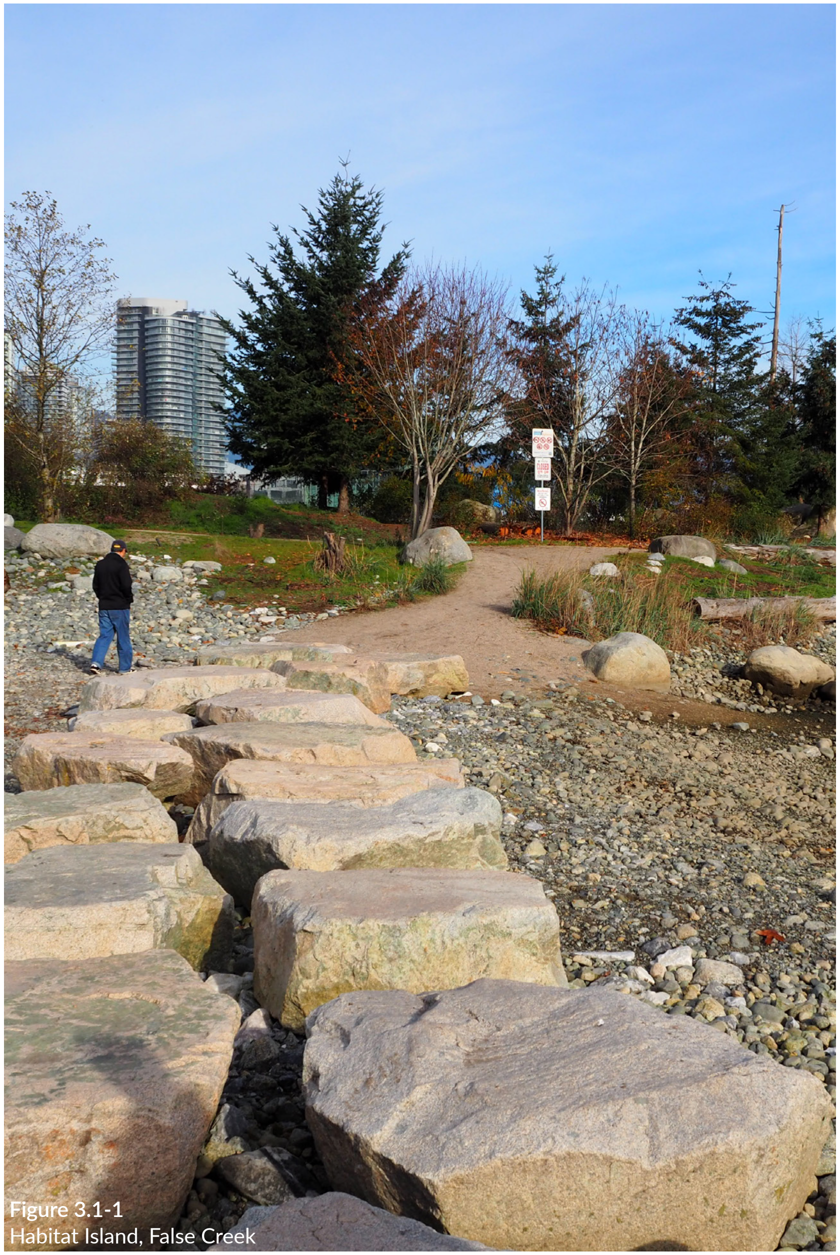


Figure 3.1-1
Habitat Island, False Creek

Figure 3.1-2
Marking High Tide, David Lam Park

Figure 3.1-3
Terraced walkway, False Creek

Design approaches for sea level rise often include measures to protect or adapt the built environment to sea level rise, or retreat from it.

Retreat is moving people and structures out of flood-prone areas, and can often include restoring the landscape to pre-development conditions. Protective measures include the use of dikes, seawalls, floodgates, where the intent is to keep water out of the protected area. Adaptive measures include raising the elevation of buildings above high water levels associated with extreme flood events. It can also include measures to reduce the pressure on stormwater and sewer infrastructure by using green infrastructure, such as bioswales, retention ponds, and rain gardens that give the landscape time to absorb some of the water, while also slowing the movement of water towards drainage infrastructure.

To determine an appropriate flood resilient approach for False Creek Flats, three case studies are reviewed that incorporate the 'protect', 'adapt', and 'retreat' approaches, including the Blue Acres Buyout Program in New Jersey, USA; the park of Corktown Common in Toronto, Canada; and the redevelopment project of HafenCity in Hamburg, Germany. To further understand how False Creek Flats can adapt to changing sea levels and adjust to more intense storms due to climate change, approaches related to green infrastructure, such as low impact development best practices, living shorelines, and coastal wetlands are also reviewed.

Figure 3.1-4 (Right)
Strategies for Sea Level Rise

The diagrams to the right illustrate the four primary strategies to deal with sea level rise. Although the 'transformation' approach is not listed, public awareness on the risks associated with flooding are often incorporated into these approaches whether it be through public engagement or educational campaigns.

Retreat

- Withdrawal, relocation, or abandonment of land and buildings
- Adaptive when reducing the need for structural protection
- Can include the relocation to areas with lower flood risks
- Discourages development in vulnerable areas exposed to sea level rise (Arlington Group Planning + Architecture Inc., 2013, p. 4)

Protect

- Keep water out and protects people, property, and infrastructure
- Involves structural mechanisms (i.e. dikes, floodgates, seawalls
- Increasingly and prohibitively expensive with sea level rise
- Limited long-term effectiveness (Ibid., p. 3)

Adapt

- Continued occupation of coastal flood prone areas
- Requires changes to infrastructure, buildings, and human activities
- Makes room for water (Ibid., p. 3)

Avoid

- Preventing development in areas vulnerable to sea level rise and flooding
- Implemented/legislated with 'no build' areas in government plans
- May involve buyouts or transferring development rights to low risk areas (Ibid., p. 4)

3.2 Robust Approach

Retreat Case Study - Blue Acres Buyout

Between October 29 to 31 in 2012, Superstorm Sandy tore through the northeast coast of the US and made its way as far north as the Great Lakes (Halverson, 2013, p. 15). Initially starting as a tropical cyclone in Cuba, when Sandy made its way north it intersected with a cold front that transitioned Sandy from a tropical cyclone to a extratropical cyclone, a hybrid superstorm that combined tropical hurricane conditions with those of a nor'easter (Gutro, 2013). It made history in the U.S. being the only tropical storm that prompted both hurricane and blizzard warnings (Halverson, 2013, p. 16).

On October 30th, Superstorm Sandy hit Atlantic City as a Category 1 hurricane, and Jersey Shore and New York experienced wind gusts up to 90-100 mph (Ibid., p. 20). Intense winds along the coast also brought along a storm surge, bringing at its highest levels almost 2.7 to 3 metres of seawater inland (Ibid., p. 20). Also occurring at this time of year was spring tide, where in the New York City region, storm tides reached almost 4.26 metres in height (Ibid., p. 20). In November 2012, New Jersey Governor, Chris Christie, estimated the cost to recovery and repair in New Jersey to be almost $37 billion (U.S. Department of Commerce, 2013, p. 25).

When Superstorm Sandy hit New Jersey, it was the third time in three years that houses in the Woodbridge Township in New Jersey were flooded, first by nor'easter in 2010, by Hurricane Irene in 2011, and then by Sandy in 2012 (Schwartz, 2018, p. 46). By this time, some residents were ready to move out of harm's way and find alternatives to elevating their homes. The New Jersey Department of Environment Protection (NJDEP) offered a solution with the Blue Acres Buyout Program.

Blue Acres Buyout Program:

The Blue Acres Buyout Program emerged out of the NJDEP's Green Acres program in 1995, when the public voted to start a fund to help buyout flood-prone properties (Bostock, 2017). In 2010, the program was eligible for funding from the Federal Emergency Management Agency (FEMA, 2015), and since Superstorm Sandy, the program has also become eligible for funding from other government agencies (Ibid.). The voluntary program allows eligible homeowners to decide whether or not to sell and relocate, and operates under three main goals:

- move people out of harms way;
- remove buildings and restore the landscape to open space so the ground can absorb water to mitigate flood risk; and
- make the land publicly accessible (Schwartz, 2018, p. 49; State of New Jersey Department of Environmental Protection, n.d., p. 1).

To facilitate the buyouts, the State of New Jersey focused on residential communities that experienced flood damage from Superstorm Sandy, or that have had "repeated flood damage from previous storms" (State of New Jersey Department of Environmental Protection, n.d., p. 2). The neighbourhoods also required support from the local government, as the buyouts result in lost tax revenues with houses being demolished and returned to open space that the local government then has to manage (Schwartz, 2018, p. 49). The State also prioritized buyout clusters over individual ones to maximize the impact of mitigating floods (Ibid., p. 49).

Fawn McGee, the Director of the Blue Acres Buyout Program, identified the success of the program as being able to assign case managers to help homeowners throughout the entire process from application to demolition, while also having a team to expedite the process, from being able to carry out appraisals, surveys and other related legal services (Ibid., p. 49). The buyouts in Woodbridge were so successful that in 2014 the Township became one of Blue Acres' largest buyout project (Ibid., pp. 53-54). By 2017 there were over 900 properties eligible for buyouts, more than 800 offers made, 639 offers accepted, 576 offers closed, and 452 houses demolished and returned to open space throughout New Jersey (Bostock, 2017). In 2018, Woodbridge had just over 140 offers accepted, and 115 properties demolished accounting to approximately 30 acres of land (Schwartz, 2018, p. 54). FEMA has also recognized the program as a best practice in flood mitigation (FEMA, 2015).

Another major contributing factor to the success of the project was securing funding, not only through the Blue Acres fund but also through FEMA and other government agencies (Bostock, 2017). In 2015, FEMA reported that Blue Acres secured "... $273 million in federal disaster recovery funds for acquisitions, including $169 million from FEMA's Hazard Mitigation Grant Program (HMGP); $100 million from the U.S. Department of Housing and Urban Development's Community Development Block Grant – Disaster Recovery program; and $4 million from the U.S. Department of Agriculture – Natural Resources Conservation Service" (FEMA, 2015, p. 1). McGee also credits the relationship building with homeowners and communities to gain support for the project and as they go through the buyout process (Bostock, 2017).

Challenges with Managed Retreat:

Managed retreat is not a popular strategy to respond to climate change. Not only is it difficult for families to uproot their lives, from their homes and community, but the buyout process can also be lengthy and expensive, which can deter people to sell if grants become available to rebuild or repair their homes, or if families are unable to afford alternative housing in the interim. Schwartz notes that buyouts can also "invoke fear, among citizens in every political stratum, bringing to mind land grabs, racist resettlement projects, class warfare, and depending on your ideology, either federal overreach or federal abandonment" (Schwartz, 2018, p. 47).

Although the decision to sell is deeply personal, studies on buyouts have shown that residents often look to their neighbours in deciding whether or not to participate in the programs (Ibid., p. 52). Helping homeowners make the tough decision to sell can often depend on grassroots support and having neighbours help educate and empower each other on the risks of living in areas vulnerable to sea level rise (Ibid., p. 52).

Further deterring people from participating in the program is when homeowners are upside-down on their mortgages, meaning that their house is worth less than the amount of money owed. McGee identified that approximately 10 to 15 percent of homeowners eligible for buyouts were upside-down on their mortgages (Bostock, 2017). To help homeowners, the Blue Acres team negotiated with lenders to facilitate shorter sales and to accept negative equity of the houses prestorm value (Ibid.). Through the Blue Acres efforts "more than $54 million of debt forgiveness" was granted, helping facilitate more buyouts (Schwartz, 2018, p. 49).

Other challenges include the uncertainty of how much time communities have to prepare for climate change. Projections estimate that sea level rise at the New Jersey coast will increase by almost two metres by 2050, although projections are less clear after that (Ibid., p. 52). Schwartz (2018) notes that by the year 2100, sea level could rise between 0.9 to 3.66 metres. This uncertainty makes it difficult for municipal leaders to plan for climate change when the public is looking for concrete answers, and options like managed retreat are politically controversial (Ibid., p. 52). A lot of this uncertainty is also the result of not fully understanding the stability of the West Antarctic ice sheet, as the volume of water it holds can easily add 3.0 metres to sea level rise (Ibid., p. 52). To gain a better understanding of the implications of the West Antarctic ice sheet holds, much work is currently being done by NASA and scientists from around the world to study the ice to gather more accurate projections, which then can be used by communities to plan for future sea level rise (Ibid., pp. 52-53).

Disaster amnesia can also pose challenges to move residents out of harm's way permanently. If there is not enough funding, or the process takes too long, some homeowners may look at alternatives to relocating, by either repairing or rebuilding in flood-prone areas (Ibid., p. 49). However, local governments can help discourage this through land use controls, such as zoning, to either prohibit rebuilding or requiring new development to comply with costly floodplain standards to prevent flood damage to structures. The township of Woodbridge did this with their Open Space Conservation/Resiliency Zone (Township of Woodbridge, 2018). This ordinance prevents new structures from being built, allowing passive recreation in unimproved open space with the primary purpose of flood mitigation. Any new landscaping in the zone requires compliance with the Floodplain Restoration Plan, based on its habitat composition (Ibid., 2018).

In seeking advice on what do with the land after the bought-out houses were demolished, the Woodbridge Township reached out to Rutgers University's Cooperative Extension, a department that "assist New Jersey communities with science-based projects" (Schwartz, 2018, p. 54). There often is little discussion on what happens after the houses are demolished in a buyout area, other than residents and communities just wanting to see the areas returned to nature (Ibid., p. 54) However, as noted by some academics, nature can mean different things to different people, and sometimes letting nature take over can have unintended consequences. For example, for Woodbridge, this might result in the land being overtaken by invasive reeds, which can create thick, dense mats that might make flooding worse in the area (Ibid., pp. 54-55). To ensure this would not happen, Woodbridge Township collaborated with Rutgers Cooperative Extension, to develop a plan to restore the area to buffer against future floods, by using green infrastructure.

Open Space and Floodplain Restoration Plan:

The Woodbridge Township Open Space and Flood Plain Restoration Plan provides a number of recommendations and directions for the newly created open space generated through the buyout process (Woodbridge Township, 2016). The plan emphasizes flood storage and stormwater infiltration; increasing the use of native vegetation to improve ecological services; and providing passive recreational opportunities for residents to enjoy the new open space (Ibid., p. 2).

The plan identifies that flood storage is created with the properties acquired from the buyout project and will help protect the neighbourhood from future storms through its connection to the drainage systems within the region (Ibid., p. 14). The plan recommends the use of green infrastructure to manage stormwater, through the use of bioswales, stormwater wetlands, and vernal ponds, which also improve water quality prior stormwater draining into surface waters (Ibid., p. 18). The floodplain restoration plan also identifies that there are a number of endangered species within, or travel through the open space area and that incorporating native vegetation and salt marsh restoration can help improve habitat quality while also maximizing the ecological service potential of the area. The native vegetation also helps ensure plant survival success and helps reduce the area being taken over by invasive species (Ibid., p. 13).

Providing recreational opportunities is also a vital component of the plan, in providing access to the open floodplain area to improve connectivity throughout the neighbourhood, a trail network also allows people to engage with nature (Ibid.). As not all the properties have been bought out in the floodplain, the plan also suggests temporary recreational opportunities and pocket parks for the parcels in between remaining houses, such as community and butterfly gardens or extended backyards, provided they remain free of built structures (Ibid., pp. 25-28).

The takeaway from this case study for False Creek Flats is that it demonstrates that although managed retreat is challenging, it is possible provided the right support and funding is available for property owners.

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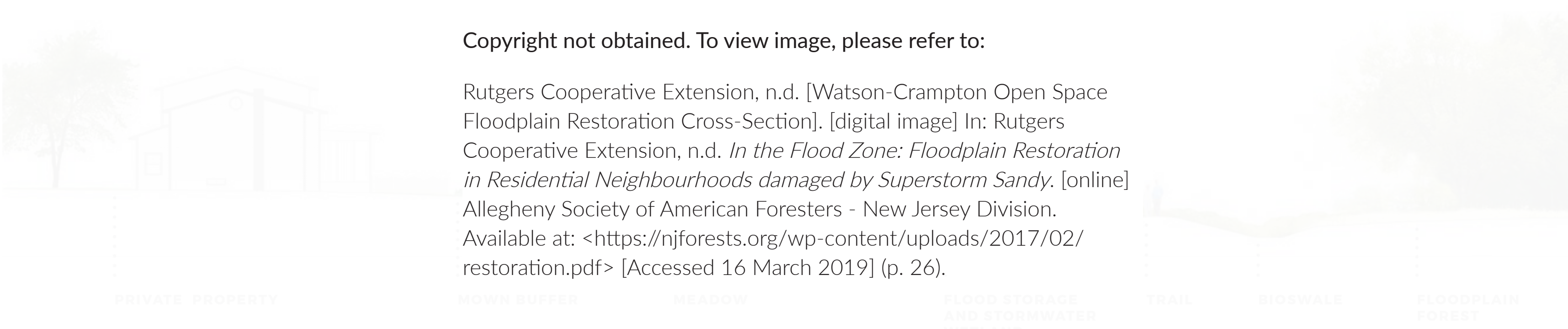
Rutgers Cooperative Extension, n.d. [Watson-Crampton Open Space Floodplain Restoration Plan]. [digital image] In: Rutgers Cooperative Extension, n.d. *In the Flood Zone: Floodplain Restoration in Residential Neighbourhoods damaged by Superstorm Sandy*. [online] Allegheny Society of American Foresters - New Jersey Division. Available at: <https://njforests.org/wp-content/uploads/2017/02/restoration.pdf> [Accessed 16 March 2019] (p. 24).

Figure 3.2-1
Watson-Crampton Open Space Floodplain Restoration Plan (Rutgers Cooperative Extension, n.d.)

The Blue Acres Buyout project also demonstrates that addressing sea level rise will involve making difficult decisions; however, the floodplain restoration plan developed by Woodbridge Township and Rutgers Cooperative Extension shows that not all is lost, and new opportunities can emerge. The new open space not only makes room for water, it is multi-functional in that it improves the restored ecological systems with native vegetation and the restoration of salt marsh wetlands, helping local wildlife; and gives people an opportunity to engage with nature by making the open space accessible.

Creating opportunities for people to engage with the landscape also allows people to learn about the local ecosystems and how it relates to the larger natural systems. Allowing people to see how the existing development transitions into the floodplain also supports an awareness of how people can work and live with natural systems, which can facilitate community resilience by helping the public understand the implications of climate change while also demonstrating ways to manage the risks associated with sea level rise.

Figure 3.2-2
Watson-Crampton Open Space Floodplain Restoration Cross-Section
(Rutgers Cooperative Extension, n.d.)



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Protect Case Study - Corktown Common

Corktown Common is a park in Toronto that uses landscape infrastructure to protect lands from flood risk from the Don River. Corktown Common evolved out of the Lower Don River West Remedial Flood Protection Project and is the catalyst for the redevelopment of the West Don Lands to the east, a brownfield site that is transforming into a mixed-use development bringing new commercial space and up to 6000 residential units to the area (Waterfront Toronto, n.d.). The project was approved in 2005 and provided a strategy to incorporate a landform flood barrier to protect and remove 210 hectares of land extending as far west as the CN tower and north towards Queens Street, from the Regulatory Floodplain (Dillon Consulting, 2005a, pp. 2 -15). Corktown Common is part of a series of projects in the area that have the overall goal to mitigate flood risk and renaturalize the Don River, and is driven by Waterfront Toronto's task to revitalize Lake Ontario's waterfront (Landscape Performance Series).

Close to Toronto's downtown and waterfront is the West Don Lands, a highly valued brownfield site; however, flood risk to the area has inhibited redevelopment (Ibid.) Flood risk in the Lower Don River floodplain has become more intense with years of urban development within the watershed between the headwaters from the Oak Ridges Moraine to the mouth of the Don River at Lake Ontario. Urbanization takes room away from where the water can go and generates stormwater runoff that is not readily absorbed into the landscape before it reaches the river, which can cause flooding during intense storms. The worst flood on record in Toronto was from Hurricane Hazel in 1954, a flood so fierce it defines the limits of flooding in the Don River watershed used by the Province of Ontario (Dillon Consulting, 2005b, p. 4).

Three factors informing the approach to remove 210 hectares of land westward of the Don River from the Regulatory Floodplain, included whether or not the plan would:

- Achieve the flood protection of the 210 hectares of land designated as the Spill Zone 3 Lands;
- Meet provincial floodplain policies and technical requirements for a permanent solution; and
- Be technically feasible/proven (Dillon Consulting, 2005c, p. 6-7).

Some of the approaches considered other than the flood protection landform included:

- Construction of a floodwall or dike along the Lower Don River;
- Implement a series of flood control reservoirs upstream of the Lower Don River;
- Floodproofing individual structures within the floodplain; and
- Dredging the river to increase its hydraulic capacity (Ibid.)

Out of twelve approaches studied, five met the criteria, which then underwent an assessment for their physical, biological, cultural, socio-economic, engineering/technical, and financial impacts (Ibid., p. 13). Through these considerations, the flood protection landform seen today emerged as the best option. This approach also included work to the east bank of the Don River, to protect against a slight increase in flood levels from the landform barrier; and a culvert under the CN Rail embankment, to increase the hydraulic capacity for diverted floodwater from the Don River while also providing pedestrian access through the rail right-of-way (Ibid., pp. 2-3). The environmental assessment for the preferred approach identifies many advantages of this option including:

- Minimal noise and air quality effects
- Opportunities to clean contaminated lands
- Enhancement of the sediment transport in the Lower Don River
- Limited loss of vegetation and impact on existing archaeological features
- Prospects for the creation of new habitats, green spaces and recreation, as well as improving connectivity and enhancing views
- Minimal impact to existing land uses
- Does not constrain future opportunities to re-naturalize the Lower Don River
- Adaptable to respond to changes in river flows due to climate change
- Easily implementable with a low risk of failure, and
- Lowest capital and maintenance costs compared to the other options (Ibid., pp. 33-34).

Although the flood protection landform extends four metres high with roughly 170,000 cubic metres of clay soil and fill, additional soil (approximately 35,000 cubic metres) provides the necessary grading for servicing the West Don Lands (Dillon Consulting, 2005d, p. 18). Further capitalizing on the opportunities the landform offers, it also serves as a park amenity and a focal point of the West Don Lands. To enhance the ecological and social value of this park, an additional 46,000 cubic yards composed of eleven different types of horticultural soil were installed to increase the height of the mound and provide the necessary medium to support five different planting zones (Landscape Performance Series, n.d.). The planting zones include five groups: “woodland, trees in pavement, marsh, lawn, and urban prairie” which create a diverse planting palette, and a range of experiences for people using the park and habitat for animals and insects (Ibid.). The constructed marsh, which helps capture stormwater runoff, provides habitat to 13 endangered migratory bird species that travel through Toronto along the Atlantic and Mississippi Flyways, and the elevated park offers new views to see the city from, enhancing the identity of the park and the sense of place it provides (Ibid.).

The park has two distinct areas, the ‘wet’ side, and the ‘dry’ side, which are separated by the crest of the landform. The ‘wet’ side is adjacent to the Don River and will have exposure to future flooding, and most of the planting on this side consists of prairie grasses to ensure the roots do not jeopardize the integrity of the landform, while also providing stabilization to prevent erosion (Hogan, 2016). The 'dry' side, which is protected by the landform, features a variety of hills and open lawns creating diverse landscape opportunities and experiences for visitors. This area features the constructed marsh that manages and filters stormwater runoff on the site and receives treated water from the splash pad located at the pavilion (Landscape Performance Series, n.d.).

The park incorporates a variety of sustainable features as it relates to water management. For example, instead of directing water from the splash pad to the Don River, underdrains move the water to a storage facility under the pavilion that treats the water with UV filters to remove bacteria and viruses, including *E. Coli* before it makes its way to the constructed marsh (Ibid.). The marsh not only provides habitat for birds, it also collects and stores treated water from the splash pad and stormwater runoff from the site, helping alleviate pressure on stormwater and sewer systems. When there is too much water, it is released by a weir towards an irrigation cistern under the central lawn (Ibid.). The constant movement of water also prevents the development of algae and eutrophication.

The park features a variety of experiences for users, including walking paths that meander through the various micro-habitat planting areas, open lawns and a pavilion with a splash pad providing space for both passive and active recreation.

This case study is particularly relevant to the False Creek Flats site in consideration of an approach to protect areas from flood risk. Using the landform berm to deflect flood waters from the Don River towards Lake Ontario to protect the park and the West Don Lands from flood risk is a landscape-based strategy that also showcases the opportunities infrastructure can create. In Corktown Common the landform berm became an amenity for the neighbourhood and also provides ecological value by offering a variety of habitats for animals, birds, and pollinators.

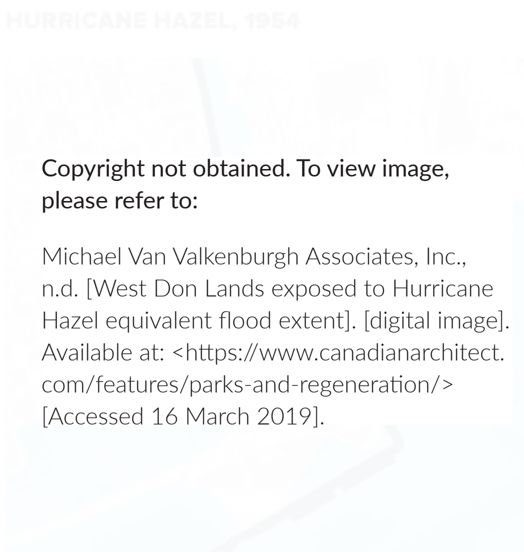

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Figure 3.2-3
West Don Lands exposed to Hurricane Hazel equivalent flood extent (Michael Van Valkenburgh Associates, Inc., n.d.)

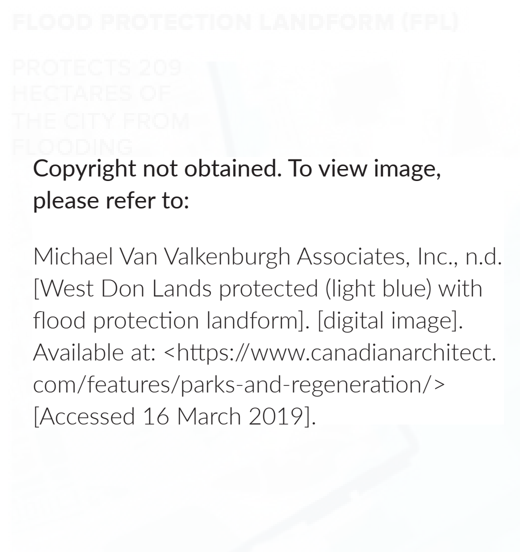

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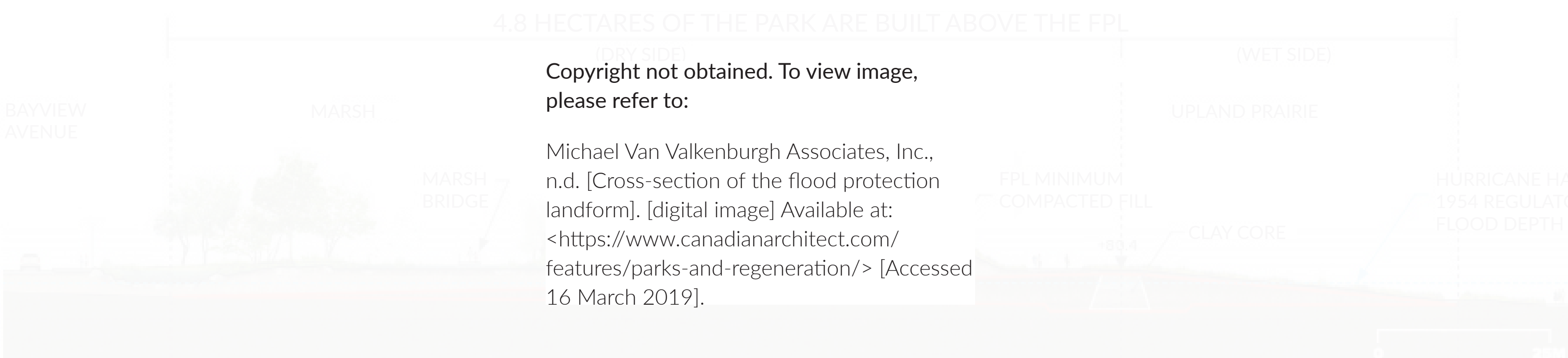
Figure 3.2-4
West Don Lands protected (light blue) with flood protection landform (Michael Van Valkenburgh Associates, Inc. n.d.)



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Michael Van Valkenburgh Associates, Inc., n.d. [Cross-section of the flood protection landform]. [digital image] Available at: <https://www.canadianarchitect.com/features/parks-and-regeneration/> [Accessed 16 March 2019].

Figure 3.2-5
Cross-section of the flood protection landform at Corktown Common (Michael Van Valkenburgh Associates, Inc., n.d.)

3.3 Adapt Approach

Adapt Case Study - HafenCity, Hamburg

HafenCity is a district located centrally in Hamburg, Germany, on a historical port site on the north side of the River Elbe. It has a long history of being an economic and industrial hub, although stifled during the Cold War when inland trade was blocked (Hall and Falk, 2014, p. 96). During the 1970s and 1980s, the port activity declined “as the port moved out to huge container-ship basins on the southern bank of the river Elbe, [and the] ... small innermost dock basins became redundant” (Hall and Falk, 2014, p. 98).

Much of the inner city had to be rebuilt after the Second World War, and after the fall of the Berlin Wall, Hamburg started to regain its economic position even after much of the central business districts residents left the area (Ibid., p. 98). To attract investment and people back to the city’s centre, Hamburg’s mayor commissioned a study to transform 157 hectares of the docklands into a high-quality mixed-use district. This study led to a plan that would enlarge the city centre by 40 percent, provide residence to 12,000 people, and increase the labour force by 40,000 (Hall and Falk, 2014, p. 98; HafenCity Hamburg GmbH, 2017, p. 5).

Informing the 25-year development process, the master plan for the project proposed:

- A strong interaction between buildings and the water;
- Elevating buildings for flood protection;
- A focus on fine-grained mixed uses; and
- An emphasis on the public realm through ground oriented uses, over 10 kilometers of new waterfront, and 26 hectares of public parks, squares, and promenades (Hall and Falk, 2014, p. 99).

With exposure to the tidal dynamics of the River Elbe, buildings and roads are built on elevated plinths 7.5 to 8.3 metres above sea level (HafenCity Hamburg GmbH, 2017, pp. 5 - 53). The decision to elevate the new development was chosen as it would incur fewer upfront costs and allow for quicker development timelines, in contrast to a polder solution where development has to wait until flood walls and barriers are in place before any construction can commence (Restemeyer et al. 2015, p. 55). Further, constructing dikes would have taken away from the waterfront atmosphere of the area (HafenCity Hamburg GmbH, 2017, p. 53). The additional space within the plinths provides space for flood protected parking garages while also taking away the need for surface parking, and temporary floodgate-like infrastructure protects windows and doors in the lower levels of the development (Restemeyer et al., 2015, p. 56).

To maintain the connection with the water, the elevation of pedestrian and cyclist promenades match the original dock levels, 4 to 5.5 metres above sea level, and floating pontoons at the Traditional Ship Harbour rise and fall with the water, providing a public amenity space engaged with the water dynamics and mooring for boats (Hall and Falk, 2014, p. 100; HafenCity Hamburg GmbH, 2017, pp. 10-11). The varying levels within public spaces provide for a variety of uses; for example, the Magellan Terraces step down to the water and create an amphitheater-like setting. The promenades link to the larger open spaces and provide a unifying element throughout the district.

To help achieve the vision of the project, Hamburg strategically acquired land and buildings during the study. Ownership of the property and structures help afford the Hamburg City Council control of the project to achieve the quality they desired (Hall and Falk, 2014, pp. 98-99). Development is also able to occur at a quicker pace with HafenCity Hamburg GmbH providing developers with planning briefs, basic infrastructure, and public amenities (Hall and Falk, 2014, p. 100), helping alleviate some of the risk that developers are faced with when taking on projects.

The HafenCity case study is helpful in considering how False Creek Flats can adapt to sea level rise by showcasing an approach that doesn't shy away from rising waters, but makes room for it, while at the same time uses infrastructure to reduce the risk of flood damage. Although the City of Vancouver has implemented the 4.6 metre flood construction levels to help minimize the impacts of flooding in False Creek Flats, it does not provide a significant area for flood waters, or opportunities to engage with the water to create a sense of place to enhance the public realm. HafenCity achieves this through the terraced promenades along the waterfront where there is a dynamic relationship of areas that can be used depending on the water levels. This case study is a great example of showing how development can coexist with a dynamic tidal environment.

Figure 3.3-1
Buildings at Sandtorkai, HafenCity, Hamburg, Germany

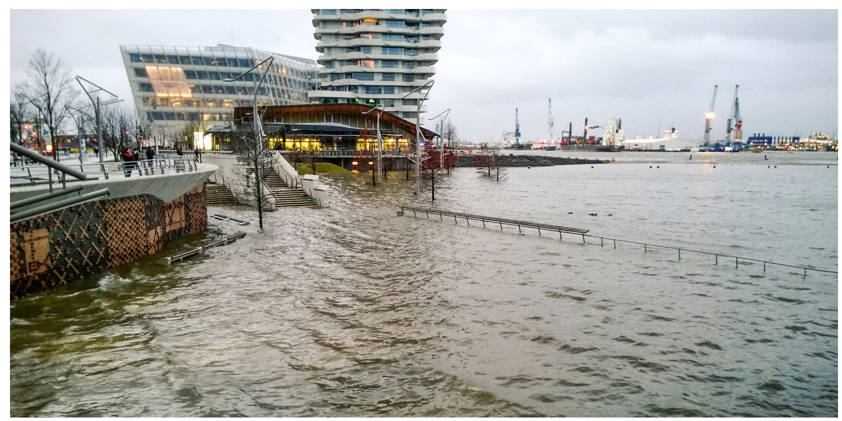

Figure 3.3-2
Flood Marco-Polo-Terrassen Hamburg HafenCity December 2013

Green Infrastructure

There are various definitions (Benton-Short et al., 2017, p. 2) for green infrastructure; however, green infrastructure relates to the use of natural and semi-natural systems to provide environmental, economic, and social benefits and services. Often green infrastructure is managing or connecting to a variety of water systems, such as surface water, stormwater, groundwater, recycled water, rivers, lakes, and oceans (Pitman et al., 2015, p. 98).

Pitman et al. (2015, p. 98) describes plants, water, and animals as being fundamental to the function of green infrastructure. Plants provide a variety of services, including reducing air temperatures, providing shade, cleaning and managing water, reducing noise and wind, reducing air pollution, sequestering carbon, remediating soils, and providing habitat for animals (Ibid., p. 98). Animals are integral for the green infrastructure system by breaking down waste through decomposition, cycling nutrients in soils, pollinating plants and dispersing seeds among other ecological services (Ibid., p. 98). Further, the diversity of plants and animals make natural systems more resilient to environmental and human-caused disturbances (Ibid., p. 99). In addition to plants and animals, soils are an essential component for green infrastructure, by providing structural support, filtering and storing water, providing nutrients and a medium for plants to grow, habitats for animals and insects, among other roles.

As green infrastructure operates at multiple scales, connecting and integrating with various systems, it provides numerous benefits. The scales that green infrastructure operates ranges from backyard gardens to boulevards, parks, greenway corridors, plazas, roof gardens, and wetlands, and integrates with larger systems, such as urban forests and watersheds (Ibid., p. 98). As a useful approach to manage the impacts of the built environment, green infrastructure has a vital role in climate adaptation.

Climate change is increasing temperatures, affecting the hydrological cycle and changing the frequency and intensity of precipitation and drought. These changes are having a ripple effect on everything from sea levels, to snow packs, river flows, the water column in lakes, freeze and thaw cycles, the number of growing degree days, to the distribution and survival of marine and terrestrial ecosystems (British Columbia Ministry of Environment, 2016). Some of the ways that green infrastructure helps communities adapt to climate change include: using trees to counteract rising temperatures and the urban heat island effect through shading and evapotranspiration; using vegetation and soils through low impact development to manage and clean stormwater runoff; creating and conserving green spaces in urban environments; creating public amenities and habitats and corridors for wildlife; and using or constructing coastal wetlands to defend shores from sea level rise and storms while providing habitats for wildlife (Pitman et al., 2015).

To identify green infrastructure approaches that could be used to manage flood risks in the False Creek Flats, low impact development and living shorelines are explored further.

Figure 3.3-3
Daylighted creek, Victoria

Low Impact Development

Low Impact Development (LID) is an approach to land development that minimizes impacts on the environment, particularly the hydrologic system through stormwater management. LID focuses on reducing the energy and speed of stormwater runoff by addressing it at the source and conveying (moving) it to catchment areas for either storage or treatment before it is released back into the water system; LID also treats water to help remove pollutants. To be most effective, LID should be considered at the initial planning stages for development, and Davis and McCuen (2005, p. 338) describe four main principles of LID:

- Maintaining existing natural features and topography that support the existing hydrologic processes;
- Limiting land clearing, disturbances during construction, and impervious surfaces to maintain natural processes;
- Employing integrated management practices (LID facilities) for post-development sites to maintain water quality and support natural drainage processes; and
- Pollution prevention.

Often land disturbance will reduce groundwater recharge by decreasing the ability of the land to allow the infiltration of water. Impervious surfaces exacerbate this by preventing infiltration while increasing the movement of water off the site. Keeping impervious areas to a minimum helps reduce runoff by keeping water on site as long as possible, allowing other processes of the hydrological cycle to occur, such as infiltration and evaporation. Focusing on small-scale source control of stormwater on developed sites can collectively minimize the impact of development stormwater runoff, help improve the quality of water re-entering the water network, and reduce the dependence on large scale infrastructure. It can also reduce the need for "large, end-of-pipe controls such as ponds, that have been traditionally employed for stormwater management" (Davis and McCuen, 2005, p. 339).

Reducing pollution from stormwater runoff can be a challenge, however, addressing pollution at the source, and "specific sources of the pollutants from becoming part of the landscape," is more effective than trying to remove pollutants from a water body (Ibid., p. 339). Often LID uses vegetation and soil to treat, convey and store stormwater; however, some LID facilities use containers, such as cisterns and rainwater barrels, to temporarily hold stormwater for later use or to delay the release of rainwater into the drainage system. Swales and depressions allow for on-site storage and infiltration, and with vegetation, these features also allow for evapotranspiration. Trees also allow for the interception of rain, slowing down the movement of water, and evapotranspiration helps lower temperatures. Further, Davis and McCuen (2005, p. 340) note that stormwater runoff velocity is "lowered due to the vegetation, depressions, and meandering, which mobilizes fewer pollutants, and possibly allows particulate matter to settle or be filtered."

In design, three main goals of LID are to:

- Slow the speed (flow velocity) and reduce the volume of stormwater runoff;
- "Improve runoff timing considerations, and"
- Improve the water quality of excess runoff (Davis and McCuen, 2005, p. 340).

One way to reduce the imperviousness of a site is to reduce the footprints of buildings, roads, sidewalks, driveways and parking lots. Davis and McCuen (2005, p. 340) describe some of the methods to reduce footprints such as "building up, instead of out", placing driveways as close as possible to roads, designing driveways and parking lots efficiently to reduce the surface area, and making sidewalks "short, narrow, and non-contiguous" (Ibid., p. 340). A method to increase the permeability of driveways and sidewalks is to use pavers, or newer technologies for porous paving and concrete, which allows water to move through the surface provided sediment is kept away from the surface (Ibid., p. 342).

Another method described is reducing the slope of surfaces through grading, as this will keep water on the site longer, allowing for more infiltration, and distributes the sheet flow to minimize channeling (Ibid., p. 340). Further, using more trees and shrubs, especially those common to the natural landscape, helps reduce the need for additional watering, pesticides, and fertilizers (Ibid., p. 341). Bioswales can also be used in parking lots to help break-up the surface area to interrupt and slow stormwater runoff (Ibid., p. 345).

When developing a site, the use of heavy equipment should be planned out in consideration of LID facilities or structures for the site, as equipment results in soil compaction (Ibid., p. 339). Davis and McCuen (2005, p. 341) note that when this happens, soils "should be tilled, and all soils can be amended with sand or organic matter to encourage higher infiltration rates." In urban areas, where space is at a premium, smaller LID practices can be used to address stormwater through the use of cisterns, tree box filters, and green roofs. Green roofs, for example, can incur a higher upfront cost; however, higher land values may justify its application to meet stormwater management targets (Ibid., p. 344). Downspouts can be disconnected from storm sewer systems and instead be directed to cisterns and rainwater harvesting structures. The water collected can then be used for non-potable uses, such as irrigation for landscaping on site, and in some cases grey water for use in toilets or other applications. Once water is collected in these structures, it can be directed to other LID facilities such as tree box planters, rain gardens, or bioswales, which can allow for infiltration, and water uptake by vegetation.

In urban areas, trees can be planted in concrete structures with high permeable soils, and contain an underdrain connected to the storm sewer network (Ibid., p. 344). Stormwater runoff from roads can also be directed into tree box planters or curb bump outs with the same intention for infiltration, evaporation, and evapotranspiration. These planters also improve water quality downstream by trapping or removing pollutants. Curb bump-outs also usually include check dams, which help slow the movement of water. One primary consideration, however, for LID features is to ensure that it does not become overloaded with sediment, which may affect its performance. To address this, the inlet of LID facilities should have a pretreatment section that can help trap sediment, such as a grass filter-strip small section of concrete with gravel or stones that can collect the sediment prior water moving into the LID facility (City of Edmonton, 2014, p. 72).

Perception and buy-in from property owners also contributes to the performance of a LID facility. If the design of the facility visually enhances its surroundings, the public will not be adverse to the use of LID in the landscape or perceive it to be unmaintained. Some level of public education or awareness may also be needed to improve perceptions. Understanding the intent and function of LID features not only improve the connection people have to the environment but also can help make the public willing to pay or invest in it, which can encourage developers by reducing the risk of or maintaining their return on investment (Davis and McCuen, 2005, p. 349).

LID facilities are also not maintenance-free, and often require monitoring, as such landowners must be aware of the function and performance of LID facilities on their properties. As Davis and McCuen (2005, p. 349) identify, “without cooperation of the landowners, many of the LID techniques will eventually fail.” To ensure success, it is imperative that prior to the installation of a LID facility, a maintenance plan has been thought out.

Vancouver’ Stormwater Management Plan

As people are becoming more aware of the impact of development on the environment, and the cost to maintain and construct infrastructure continues to rise, cities are looking towards low impact development to help manage the costs of managing stormwater, while also to reduce the environmental impact of urban environments. Many cities are starting to create their LID guides for implementation, including the City of Vancouver where low impact development is an integral part of its Integrated Stormwater Management Plan.

The Integrated Rainwater Management Plan (IRMP) is a plan to address the management of stormwater in the city and to improve water quality in the “receiving waters including False Creek,” English Bay, Coal Harbour, and the Fraser River (City of Vancouver, 2016, p. 1). The plan manages most of the watershed except for two watersheds with surface streams, including Still Creek and Musqueam Creek, as well as Stanley Park, which have their own stormwater management plans (Ibid., p. i). The IRMP supports higher policy objectives, such as the Greenest City Action Plan, that has the goal of making Vancouver the “greenest city on earth by the Year 2020” and specific goals in this policy to support the green economy, green buildings, access to nature, and clean water (Ibid., p. 1). The IRMP will also:

- Support local ecosystems;
- Help the city prepare for climate change and more intense weather, such as more precipitation during the winter, dry spells and cloudbursts during the summer which will put

more pressure on the city's infrastructure designed for past peak flows;
- Protect sensitive waters for aquatic habitat and maintain water quality for recreation on beaches, through treating water and addressing sources of pollution;
- Reduce combined sewer overflows by separating sanitary sewers from stormwater and integrating best practices (such as LID) for stormwater management;
- Work towards meeting regulatory requirements by higher orders of government, such as the federal Department of Fisheries and Oceans, provincial requirements of the BC Environment and Ministry of Health, and the Metro Vancouver Integrated Liquid Waste and Resource Management Plan; and
- Will honour rainfall as a resource (Ibid., pp. 2- 8).

Implementing the IRMP considers the rainfall spectrum in Vancouver, where on average approximately 70% of the rainfall consists of light showers and smaller storms, 20% as large storms, and 10% as extreme storms that may result in flooding (Ibid., p. 9). Small and large storms account for 90% of the annual precipitation; however, most of this rainfall can be captured through low impact development facilities. The goal for the remaining 10%, which may cause flooding, is to convey the water safely to protect people and buildings from flooding (Ibid., p. 9).

To meet the goals of the IRMP, the City of Vancouver will look at ways to 'green' land use and streets through reducing the volume and velocity of stormwater runoff and reducing contaminants in receiving waters (Ibid., p. 28). It looks at addressing where stormwater falls, on trees, soils, buildings, and roads and other pavements, looking at ways to mimic ecological systems to improve infrastructure and buildings, and using green infrastructure to improve stormwater management and water quality (Ibid., p. 28), among other services. Part of employing green infrastructure is reconnecting rainfall to natural pathways, and using urban forests and soils to absorb stormwater, helping clean and slowly releasing it (Ibid., p. 29). Integrating low impact development features can help the existing landscape become more absorbent, while also providing opportunities to reuse and recycle water (Ibid., p. 29). Reducing nutrient loads into waters also helps inhibit the growth of algae and other vegetation in waterways, which can also lead to odours, decay, and affect recreation opportunities and land values near them (Ibid., p. 29). Improving water quality could help inhibit the growth of bacteria in False Creek, which not only affects aquatic habitats, it often results in beach closures along English Bay (Ibid., p. 29).

The IRMP provides guidance on the type of green infrastructure practices that can be used to improve stormwater management, as well as a matrix of the green infrastructure types and best practices for where these features are best suited in urban settings. The green infrastructure types identified include:

- Absorbent landscapes,
- Infiltration swales,

- Rain gardens and infiltration bulges,
- Pervious paving,
- Green roofs,
- Tree well structures,
- Rainwater harvesting,
- Infiltration trenches,
- Water quality structures,
- Detention tanks,
- Daylighted streams and channel improvement, and
- Constructed wetlands (Ibid., p. 30-31).

Because Vancouver watershed is primarily contained in pipes, the IRMP focuses on managing the systems that release water into tidal and estuary waters, and therefore also considers the performance of green infrastructure and methods to evaluate the performance in terms of function and costs (Ibid., p. 32). The IRMP also has specific targets relating to the rainfall spectrum.

For normal rainfall (70% of rainfall) the goal is to absorb the first 24 mm of rainfall in a day at the location where rainfall hits the ground. Green infrastructure can support this target by making landscapes more absorbent. For example, "topsoil and organic compost" can hold approximately "10-20% of its volume in rainfall" and a depth to 450 mm of soil can "hold at least 45 mm of water, where the moisture would either slowly evaporate or soak into the subsoils" (Ibid., p. 35).

For larger storms (20% of rainfall), the target is to maximize the time the water is on the land to let rainwater (up to 48 mm) infiltrate into soils, while also treating the water to improve water quality. (p. 35) Soils containing a mix of topsoil and organic compost can help facilitate the removal of stormwater pollutants, such as "petroleum hydrocarbons, heavy metals from brake linings, sediment from erosion, excess nutrients, and bacteria from fertilizers and pet/bird droppings" (Ibid., p. 35). Additional water storage is provided in an under-layer of drainage rock, and a perforated pipe can be installed at the base to direct excess water to the storm drainage system (Ibid., p. 35).

For extreme storms (10% of rainfall), the target is to convey stormwater safely, which includes rainfall more than 48 mm, and may require the conveyance of stormwater to pipes and "surface gutters along street edges, channels and overflows" (Ibid., p. 35). During intense storms emphasis is placed on safety and less so on water treatment (Ibid., p. 35).

Following is a summary of the different LID and green infrastructure types identified above.

Absorbent Landscapes

The primary purpose of absorbent landscapes is to allow for infiltration of rainfall into subsoils, which helps recharge groundwater and supports rainwater management through interception and evapotranspiration when trees and shrubs are present (City of Vancouver, 2016b, p.4). Absorbent landscapes can include anything from parks and green spaces to backyard gardens and boulevards.

To increase the area for absorbent landscapes, the IRMP (City of Vancouver, 2016b, p. 5) recommends increasing the height of buildings rather than footprints and using narrower roads and minimal parking. It also calls for a design that drains runoff from impervious surfaces into absorbent landscapes, and to slightly depress these landscapes to hold water temporarily to allow water to absorb into the ground. Adding compost to soils is also recommended, specifically 8% for lawns and 15% for planting beds, and using vegetation and organic matter to maintain soil permeability to prevent crusting of the soil's surface (Ibid., p. 5). To optimize the performance of absorbent landscape, the IRMP recommends increasing the growing medium for planting beds for additional storage and treatment of stormwater (Ibid., p. 5).

Many locations are suitable locations for absorbent landscapes, where space is permitted, such as low, medium, and high-density residential areas; commercial, industrial and institutional areas; and boulevards, parks and open spaces (Ibid., p. 5).

Figure 3.3-4
George Wainborn Park, Vancouver

Infiltration Swales

Infiltration swales are low profile channels that collect and convey stormwater, and may include small check dams or weirs to control and slow the flow of water to help encourage infiltration; however, during more intense storms, these facilities may direct water to the storm sewer network. Some swales may include a reservoir of drainage rock to hold more water and a perforated pipe connected to the storm sewer system (Ibid., pp. 6-7). Other jurisdictions refer to these features as bioswales and have the same intent to allow for absorption, evaporation, evapotranspiration, and controlled conveyance (City of Edmonton, 2014, p. 43, 93). Grass swales can also be considered infiltration swales; however, they perform less effectively for absorbing water, as they have tend to have a shallower topsoil depth in comparison to bioswales, and they typically do not include a drainage reservoir (Ibid., p. 43). Bioswales can replace, or be used in combination with curbs and gutters, and help remove particulates from water with vegetation and soil, and treat pollution through biodegradation with soil microbes (Ibid., p. 93).

To optimize performance, side slopes should be 3:1, longitudinal slopes should be between 1 and 2%, and the swale width should be between 0.6 m and 2.4 m (City of Vancouver, 2016b, p. 7). Further, pretreatment, before water enters the swale, helps prevent erosion and traps sediments; check dams should be embedded at least 100 mm; and ideal soil depths range from 150 mm to 300 mm (Ibid., p. 7). Bioswales along roads should include components to prevent water infiltration that may compromise the adjacent road structure, and swales can weave to protect existing trees (City of Edmonton, 2014, p. 94-95). A buffer or vegetated filter strips should also be used along roads to prevent the collection of sediment, and salt tolerant plants should be selected for areas with exposure to anti-icing agents (Ibid., p. 95). In Vancouver, the impervious to pervious ratio should not exceed 5:1, and due to low infiltration capabilities, native soils are not recommended for these facilities (City of Vancouver, 2016b, p. 7). Similar to absorbent landscapes, infiltration swales are well suited to a variety of sites, including low, medium, and high-density residential areas; commercial, industrial and institutional areas; and boulevards, parks and open spaces (Ibid., p. 7).

Figure 3.3-5
Bioswale, Olympic Village, Vancouver

Rain Gardens and Infiltration Bulges

Rain gardens and infiltration bulges are a form of a bioretention facility, which typically includes a depressed landscape that collects stormwater from buildings, paving, and roads. To help encourage storage, rain gardens and infiltration bulges also tend to include a drainage rock reservoir and similar to swales, they may consist of a perforated pipe that is connected to a storm sewer network to convey water during more intense storms (Ibid., p. 8). The primary purpose of a rain garden or infiltration bulge is similar to infiltration swales in collecting water from nearby impervious surfaces and encourage infiltration while also treating and reducing the flow of runoff, and allowing time for evaporation and evapotranspiration to occur (City of Edmonton, 2014, pp. 41-42). Infiltration bulges, also known as curb bump-outs, also have an overflow outlet downstream to help allow excess water to move through (Ibid., p. 42).

Design considerations for rain gardens and infiltration bulges include a lower ratio of impervious to pervious areas for land uses with higher sediment loads; using smaller disconnected rain gardens rather than large rain gardens; and locating rain gardens at least 3 metres from buildings with footing drains and not on areas with steep slopes (City of Vancouver, 2016b, p. 9). Similar to infiltration swales, pretreatment of runoff will keep sediment out of the facility and reduce erosion through a "point source inlet" with "non-erodible material", and weirs can help distribute surface flow (Ibid., p. 9). Ideal widths should maintain a 2:1 ratio with a range from 0.6 to 3.0 metres, and side slopes should not exceed 2:1, although, 4:1 is better for maintenance (Ibid., p. 9).

Soil depths should be at least 300 mm, however, 1200 mm is more desirable and should be topped with a 50 to 75 mm mulch layer (Ibid., p. 9). Utility crossings should be avoided; however, trench dams can prevent water from entering the utility trench (Ibid., p. 9). It is also recommended to place "geotextile fabric along sidewalls to help direct the flow downward and reduce lateral flows under [adjacent] pavement, when located in a media strip or in a parking lot" (City of Edmonton, 2014, p. 88). Impervious to pervious ratios should not exceed 5:1, and to ensure water does not bypass the facility, it is recommended to have a "50 mm drop in gutter profiles" and another 50 mm into the facility (City of Vancouver, 2016b, p. 9). Many areas are suitable for rain gardens and infiltration bulges including: low, medium, and high-density residential areas; commercial, industrial and institutional areas; and boulevards, parks and open spaces (Ibid., p. 8).

Figure 3.3-6
Garden at Beaty Biodiversity Centre, UBC

Pervious Paving

Pervious (or permeable) paving, allows stormwater to infiltrate either between pavers or through porous concrete or asphalt, without losing the functionality (City of Edmonton, 2014, p. 46). These facilities are designed to have a drainage reservoir beneath the pavers for storage and may include a perforated drain to direct excess water away (City of Vancouver, 2016b, p. 10; City of Edmonton, 2014, p. 46). Pervious paving also requires barriers when adjacent to buildings and roadways to prevent damage to nearby structures (City of Edmonton, 2014, p. 109).

Design considerations for pervious paving include limiting its use to low traffic areas, such as driveways, parking areas, walkways, service roads, or fire lanes (City of Vancouver, 2016b, p. 11). The maximum ratio for impervious to pervious surface should be 2:1, and additional care should be taken to ensure protection from sedimentation to maintain surface drainage through pretreatment, and pretreatment should also be used in pollution hot-spot areas (Ibid., p. 11). Soil subgrades should be tested to ensure appropriate infiltration rates, and the surface slope should be at least 1% to prevent ponding (Ibid., p. 11). It is further recommended to wrap paver bedding materials in geotextile cloth to prevent the mobilization of fine silts in the facility, and edgers should be used to contain pavers (Ibid., p. 11). Similar to rain gardens and infiltration bulges, trench dams can be used if necessary when there are utility crossings (Ibid., p. 11). Pervious paving should also undergo a vacuum sweep twice a year to maintain infiltration performance (Ibid., p. 11). Locations suitable for pervious paving include: low, medium, and high-density residential areas; commercial and institutional areas; and boulevards, parks and open spaces (Ibid., p. 10).

Figure 3.3-7
Pavers in boulevard, Olympic Village, Vancouver

Green Roofs

Green roofs are like a surface veneer over a building, that allows for both vegetation and drainage, reducing runoff flows and volumes with additional benefits such as insulation, providing heat gain reductions for the building, habitats for birds and insects, and evapotranspiration to help reduce the urban heat island effect (City of Vancouver, 2016b, p. 12; City of Edmonton, 2014, p. 101). There are two types of green roofs, intensive and extensive. Intensive roofs provide enough soil medium (usually at least 300 mm) to support larger plants, such as trees and shrubs, and can provide room for rooftop amenities, through additional structural supports in the building (City of Edmonton, 2014, p. 44). Extensive green roofs typically provide a growing medium (approximately 50 to 150 mm) that supports low growing and ground cover plants, and can be more economical through the reduced need for irrigation during summer months and need for structural support; however, this type of green roofs typically does not provide amenity space for people to use (Ibid., p. 44, 103).

Green roofs are better suited for flat roofs, although can go on roofs with a slight incline provided it doesn't exceed a 1:3 pitch (City of Vancouver, 2016b, p. 13). The design of green roofs is most effective when designing the building, so the green roof and rainwater storage loads are integrated into the structure of the building and so that maintenance access can be provided (Ibid., p. 13). Surface overflows must also be integrated to preserve the structure of the building and to prevent erosion (City of Edmonton, 2014, p. 104).

In considering plant material, it is recommended to avoid monoculture plantings, as a mix of species will be more self-sustaining, and the perimeter of the roof should be plant free to help ensure moisture does not impact the structural integrity of the building (City of Vancouver, 2016b, p. 13). Fire breaks consisting of non-combustible materials, at least 50 cm wide, should be provided every 40 metres and at roof penetrations, a root barrier should also be provided to prevent damage from plants (Ibid., p. 13). Green roofs consist of multiple layers including: "vegetation, growing medium, drainage filter, root barrier, waterproof/roofing membrane, cover board, thermal insulation, vapour barrier, and roof and building support structure" (City of Edmonton, 2014, p. 101).

Green roofs are well suited for any building; however, may be more economically viable in highly urbanized areas where limited space is available at the ground level (Ibid., p. 101).

Figure 3.3-8
Green Roof on Qualico Family Centre at Assiniboine Park, Winnipeg

Tree Well Structures

Tree well structures, tree trenches, and box planters are used to help trees and plants grow while also storing and intercepting rainwater, and improving water quality through the treatment and catchment of pollutants with soil and vegetation (City of Vancouver, 2016b, p. 14; City of Edmonton, 2014, p. 119). Box planters often consist of a concrete container, may include concrete or lining at the base, and be filled with amended soil and vegetation, such as perennials, shrubs, and trees (City of Edmonton, 2014, p. 117). Alternatively, plastic cells or soil cells may be used to provide structural support underneath sidewalks and roadways, allowing room for trees to grow in non-compacted soils (Ibid., p. 117). However, soil cells should be designed to support "the heaviest vehicle expected to travel the overlying or adjacent surface" (Ibid., p. 119). Often a perforated drain is located at the base to help direct excess water away, sometimes to a reservoir that can later be used for irrigation (Ibid., p. 118). Water directed to tree structures is either through permeable pavement, curb cuts, connection to roof drains, or through catch basins with pretreatment settling basins to collect sediment (Ibid., p. 117).

To optimize the performance of tree well structures, the trench should provide an additional 0.3 m of space around the perimeter of the structure, subgrades should be compacted to 95% density, and construction should be avoided when soils are wet or frozen (City of Vancouver, 2016b, p. 15). Root barriers, or air gaps, should also be used to prevent damage to adjacent buildings and structures, and tree grates will require opening every three years to allow room for tree growth and to replace mulch (Ibid., p. 15). Tree well structures are well suited for more urban areas, medium to high-density residential areas, commercial and institutional areas and along streets (Ibid., p. 14).

Figure 3.3-9
Trees along Maynards Block, Vancouver

Rainwater Harvesting

Rainwater harvesting facilities collect surface runoff from buildings, and store it for future non-potable uses, such as irrigation or toilet water (City of Vancouver, 2016b, p. 16-17; City of Edmonton, 2014, p. 131). Above-ground cisterns and rain barrels are easier to implement and are more cost-effective (City of Vancouver, 2016b, p. 17) than below-ground cisterns, which require care to prevent leakage and must include an overflow drain, and a clean-out port or access for maintenance (City of Edmonton, 2014, p. 131). The amount of rainfall a cistern can collect depends on its catchment area, which can be "calculated by multiplying the roof area (m^2) by a percent of average rainfall" (City of Vancouver, 2016b, p. 17). Sometimes recycled water from rainwater harvesting can be discolored, affecting the perception of its use; however, rainwater can be treated to help reduce discoloration (Ibid., p. 17).

Rainwater harvesting structures do require maintenance, including slowly releasing water from cisterns throughout the year, cleaning gutters regularly, and preventing light transmission to prevent the growth of algae (Ibid., p. 17). Tanks should also be at least three metres from building foundations and should only collect stormwater from roof surfaces to prevent the collection of "salt, bacteria, and metals" from vehicular and pedestrian areas (City of Edmonton, 2014, p. 133). Rainwater harvesting is suitable for a variety of land uses, however, the cost may make it more appropriate for commercial, mixed-use, and institutional uses (City of Vancouver, 2016b, p. 16).

Infiltration Trenches

Infiltration trenches are below-grade structures that store rainwater and allow water to infiltrate into subsurface soils (Ibid., p. 18). These facilities typically include "an inlet pipe or water source, catch basin sump, perforated distribution pipe, infiltration trench and overflow to the storm sewer" (Ibid., p. 18). Infiltration trenches require pretreatment of runoff before it enters the trench to ensure the removal of fine particles that could cause clogging over time, and because these facilities do not remove pollutants (Ibid., pp. 18-19).

Depending on the infiltration of native soils, rock trench depths can range between 0.3 metres and 2 metres and should be located at least 5 metres from buildings, "1.5 m[etres] from property lines[,] ... 6 m[etres] from adjacent infiltration systems," and at least 0.6 metres above the water table (Ibid., p. 19).

Trench widths tend to be in the range of 0.6 metres to 2.4 metres, and care should be taken to ensure trench sides and base are protected from over compaction, and the soil of the base is scarified to at least 150 mm to ensure infiltration (Ibid., p. 19). Infiltration trenches also require a sump with lid for maintenance and must include an overflow for excess water, and trench dams when utilities are present (Ibid., p. 18).

Infiltration trenches are suitable for commercial, mixed-use, industrial, and institutional uses, as well as on local streets (Ibid., p. 18).

Detention Tanks

Detention tanks collect rainwater and slowly release it after a storm event into the drainage system (Ibid., p. 22). They are located above or below ground, in tanks, pre-cast concrete vaults or oversized pipes and culverts, and provide flood storage, prevent erosion, and protect aquatic habitats (Ibid., p. 23). Pretreatment of runoff is required to remove sediment, and tanks need overflows to release excess water, and underground tanks must have a durable cover that can support above ground loads, “air space equal to 20% of the” depth of the tank, venting to the surface, and access for maintenance (Ibid., p. 23). Detention tanks are suitable for commercial, mix-use, industrial, and institutional uses (Ibid., p. 22).

Water Quality Structures

Water quality structures treat water for pollutants and typically include “oil separators, grid/sediment separators, and filter structures” (Ibid., p. 20). Oil separators allow oil to float on top of buffer plates, grit and sediment separators use gravity to help collect sediment, and filter structures use filters to remove difficult pollutants in stormwater, such as phosphorus (Ibid., p. 20). Manufacturer requirements should determine sizing and design flows should be maintained to perform optimum treatment (Ibid., p. 21). Facilities should be inspected regularly, and vacuum trucks should remove oil and hydrocarbons (Ibid., p. 21). Water quality structures are suitable for local, collector, and arterial roads (Ibid., p. 20).

Daylighted Streams / Channel Improvements

Daylighted streams and channel improvements help improve and restore aquatic and terrestrial habitats, while also providing passive recreational and educational opportunities (Ibid., p. 24). Design considerations for these types of green infrastructure include determining surface runoff patterns and planning to accommodate 100-year events while still providing sufficient “water depths and flows for aquatic species” during drier seasons (Ibid., p. 25).

Designing complexity in water channels by adding logs and other debris, clusters of rocks and boulders, and vegetation enhances the riparian environment for aquatic habitats (Ibid., p. 25). Riparian planting should also provide shade to keep streams cool and to provide additional “habitat for birds and other wildlife” (Ibid., p. 25).

Outfalls that lead into daylighted creeks should have armouring to prevent erosion, and a geotechnical assessment should be conducted prior to design and implementation (Ibid., p. 25). It is recommended that public engagement is conducted to provide “a sense of ownership to the community;” engagement also provides opportunities for education and awareness of the project (Ibid., p. 25). Maintenance and monitoring should be conducted during the first few seasons to ensure repairs are made where needed (Ibid., p. 25).

Daylighted streams and channel improvements are suitable for parks and green space, and commercial, mixed-use, industrial and institutional areas (Ibid., p. 24).

Constructed Wetlands

Constructed wetlands typically include a number of interconnected shallow ponds, which are connected by constructed marshes that "treat contaminated stormwater through the biological processes associated with emergent aquatic plants and via sedimentation" (Ibid., p. 26). Wetlands also prevent floods and stream erosion and provide habitat for aquatic and terrestrial species (Ibid., p. 26). However, treatment wetlands are not generally designed to detain water, due to the lack of space available treatment and detention, which is roughly "3 - 5% of the catchment area" (Ibid., p. 26).

Design for constructed wetlands should ensure continuous flows to prevent stagnation, sizing to allow sediment to settle, and room to accommodate "90% of the average annual rainfall runoff" (Ibid., p. 27). Wetlands should also be designed to include a sediment forebay equal to 10% of wetland area, and wetlands should include varying depths, islands, and marsh-like peninsulas (Ibid., p. 27).

The distribution of depth variation should include roughly 25% being more than 1.2 metres deep; 65% less than 450 mm deep (to provide growth of and to allow the uptake of contaminants); and 35% should be less than 150 mm deep (Ibid., p. 27). The length to width ratio for constructed wetlands should be between 3:1 and 5:1, and side slopes should not exceed 5:1 (Ibid., p. 27). Although 72% of the wetland should be continually saturated "from a 2-year 24-hour rainfall event", the detention of water should be limited to a maximum depth of 1 metre for the survival of plants (Ibid., p. 27).

Wetlands are suitable for parks and green space, industrial and institutional areas (Ibid., p. 26).

Figure 3.3-10
Constructed wetland at Hinge Park, Vancouver

Living Shorelines

Traditional structures to protect shores from erosion and damage from waves and storms include seawalls, bulkheads, revetments, and groins. Although these types of structures are common among many coastlines, their effectiveness in protecting coasts is diminishing as sea level rises. Hard coastal infrastructure also tends to have singular benefits and interrupt coastal processes, creating ecological consequences and erosion. Although structures are intended to benefit upland areas, they cause erosion adjacent to the structure and alongshore by inhibiting longshore sediment transport (O'Donnell, 2017, p. 435, Bilkovic et al. 2016, p. 162). Ecological consequences of disrupting or eliminating habitats reduces biodiversity and habitat distribution. For example, a reduction to the intertidal zone can impede the growth of submerged aquatic vegetation, which can disrupt aquatic species that depend on shallow water habitats for various stages of their life cycle (O'Donnell, 2017, p. 435). The overdependence on traditional coastal infrastructure can provide a false sense of safety and can lead to devastating effects when they fail (O'Donnell, 2017, p. 435), such as the consequence of the levee breach in New Orleans from Hurricane Katrina in 2005, resulting in more than 1800 people losing their lives, destroying or damaging more than 800,000 homes, and causing $80 billion in damages (Hurricane: Science and Society, n.d.).

As the limitations and consequences of traditional coastal protection are better understood, a shift to natural-based solutions is garnering more attention, such as the application of living shorelines as coastal defences.

Although there are a number of definitions for living shorelines (O'Donnell, 2017, p. 435), Bilkovic et al. (2016, p. 163) describes common elements and intentions of living shorelines, including: erosion reduction; wave attenuation (reducing the height and velocity of waves); creating or supporting diverse and connected habitats; and allowance for habitat migration.

Living shorelines can also provide aesthetic and recreational value for people to view wildlife (O'Donnell, 2017, p. 437), and provide passive education opportunities by making coastal landscapes and processes more visual. Because living shorelines work with nature, coastal processes tend to help strengthen their protective capacity through the growth of vegetation, or the accumulation of sediment. Living shorelines are also resilient and adaptive being able to respond to disturbances, such as storms, and regenerating over time; however, their application is context-specific, and therefore needs to be considered before determining the best use and type of living shoreline that is appropriate for a particular place.

Living shorelines can be split into two categories: non-structural, where soft materials are used, such as sand (for beach nourishment or dune creation) and vegetation (grasses for marshes or trees and shrubs for upland planting); and hybrid structures, when revetments, sills, oyster reefs, and breakwaters support non-structural approaches (Ibid., p. 437).

Soft Structural Approaches

Marshes

Marsh restoration or creation is one of the more common approaches for non-structural coastal protection for erosion control as vegetation attenuates waves and traps sediment (O'Donnell, 2017, p. 437; Bilkovic et al., 2016, p. 163). Marsh restoration can involve vegetation management, such as trimming overhanging tree branches to allow more sunlight to reach a marsh; the addition of sediment to create a slope and elevation in relation to the water level to maintain the marsh, or the planting of additional grasses to fill in gaps in sparse marsh areas (O'Donnell, 2017, p. 437). Marsh creation, however, is not recommended in areas where marshes are not a typical landscape on comparable shorelines (Ibid., p. 437). There are a number of factors that can influence the success or performance of a marsh, such as site conditions (geomorphology of the site, depth and type of soils, configuration of the shore and its exposure to water, weather and sunlight); the amount and type of vegetation present; the height of plants in relation to the depth of the water; the tidal amplitude; wave energy; marsh width and other factors, making its coastal protection performance context specific (O'Donnell, 2017, p. 443-445; Bilkovic et al., 2016, p. 164).

Studies indicate that marshes do not necessarily need to be extensive to be effective wave attenuators. Both O'Donnell (2017, p. 443) and Bilkovic et al. (2016, p. 164) suggest that fringe marshes can be as effective as extensive marshes.

Research findings by Möller and Spencer (2002 cited in O'Donnell, 2017, p. 443), and Shepard, Crain, and Beck (2011 cited in O'Donnell, 2017, p. 443) indicate that marshes can attenuate waves within the first few meters, and one study by Knutson et al., (1982 cited in O'Donnell, 2017, p. 443) found that *Spartina alterniflora*, can on average, dissipate at least 50% of small waves in the first 2.5 metres of marsh and 100% in within 30 metres of the marsh. Further, in a meta-analysis, by Shepard, Crain, and Beck (2011 cited in Bilkovic et al., 2016, p. 164), it was found that "marshes less than 10 m in width can reduce wave heights by 50-80%."

Shore Stabilization

Shore stabilization performance by marshes is dependent on sediment supply, tidal range, and elevation of the marsh which can affect the amount and time the marsh is inundated by water, and the density and height of marsh vegetation (O'Donnell, 2017, p. 444). Coastal processes, such as sediment deposition and root growth, can maintain or increase stabilization performance, and vegetation is critical to reducing erosion. A marsh that is continuously flooded can inhibit the growth of vegetation, thereby reducing biomass and root growth potential, and the ability for vegetation to trap sediment, reducing the effectiveness of the marsh to stabilize the shore (Shepard, Crain, and Beck, 2011, cited in O'Donnell, 2017, p. 444).

Tidal marshes can help minimize the impact of a storm surge by reducing the wave energy and by providing room for flood waters. O'Donnell (2017) notes that in a study by Gittman et al. (2014, cited in O'Donnell, 2017, p. 444) it was found that marshes can provide better protection against storm-induced erosion than bulkheads, and Möller et al. (2014, cited in O'Donnell, 2017, p. 444) found that vegetation can attenuate 60% of the waves generated by storms. However, there is still uncertainty on the effect of storm surge and attenuation on marshes, making it difficult to develop models for using marshes as coastal protection planning. (O'Donnell, 2017, p 444) Factors that can influence the intensity of waves and flooding include: "[m]arsh characteristics, variations in coastal geology, bathymetry and exposure, and store-specific parameters such as duration, intensity, size, and track" (O'Donnell, 2017, p 444).

There is also speculation whether or not tidal marshes can migrate landward as sea level rises as landforms, development, and infrastructure inhibit migration (O'Donnell, 2016, p. 445); however, marshes are able to grow vertically and in some cases may be able to keep pace and adapt to gradual sea level rise more effectively than mitigate erosion from short-term events, such as storms waves (Feagin et al., 2009, and Gedan et al., 2011, cited in O'Donnell, 2016, p. 445). Marshes are also able to maintain surface elevation and grow vertically through sediment deposition and organic matter accumulation (Cherry, 2018). Whether or not a marsh can maintain its surface elevation and adapt to sea level rise depends on the region, the tidal range (as it relates to the inundation of the marsh), exposure to water with high sediment concentrations, "vegetation, salinity, nutrient loading, and climate" (McKee and Patrick, 1988, and Morris et al., 2002, cited in O'Donnell, 2016, p. 445).

Slope and Bank Grading

Banks that are susceptible to coastal erosion, such as soft banks or bluff, can be regraded to a more stable slope, which can later be planted with vegetation to provide further soil stabilization (O'Donnell, 2016, p. 437). A number of factors can influence bank stability, such as soil and sediment types; angle of the slope; height; exposure to the coast, including waves, tides, sea level rise; ground and surface runoff; topography; vegetation; and upland land use (Ibid., p. 437). When coastal banks are regraded, they are often planted with salt-tolerant plants to provide soil stabilization, and when appropriate can be further reinforced at the base with a constructed fringe salt marsh in the intertidal zone (Chesapeake Bay Foundation, 2007; Hardaway et al., 2009; VIMS-CCRM, 2006, cited in O'Donnell, 2016, p. 437). However, if the site has exposure to large wave action, slope regrading and terracing will not be effective for shore protection (O'Donnell, 2016, p. 437).

Beach Nourishment and Dune Restoration/Creation

Although not always considered living shorelines, beach nourishment involves adding sediment to beaches to provide protection against waves causing erosion, to replenish a beach that has become too narrow for recreational use, or when dunes are damaged during storms, creating steep scarps that are dangerous to beachgoers (Ibid., pp. 438, 445). To help protect beaches from erosion, beach nourishment will often create wider and higher beaches, although this may not occur on recreational beaches where high elevations may impede views and recreational use (Ibid., p. 438).

In determining whether to provide beach nourishment, O'Donnell (2017, p. 438) notes considerations including that the beach will require monitoring and maintenance, and that the height of beach berms should be 0.5 metres lower than the natural level, which can then "allow natural processes to build the final berm." Other considerations include public perception and ecological consequences. As nourishment can result in significant fill being added to a beach, it is typical for a substantial amount of the fill to be transported after the first winter or after a major storm; however, if the public is not aware of this process, they may perceive the nourishment process as failing (Ibid., p. 438). Further, when sediment is added to a beach, it can affect coastal habitats and nesting sites for shorebirds, disrupt benthic ecology on sandy shores, and covering existing vegetation can create an environment to that allows invasive plants to establish (Ibid., pp. 438, 445).

Considerations for dune restoration include whether or not: dunes can form naturally; maintenance will be provided, especially after storms; there is sufficient space and sediment available for dunes to form; and measures will be taken to prevent damage from humans (Ibid., p. 439).

The height of dunes is also dependent on wave energy. Low wave-energy conditions will create lower dunes, whereas higher wave-energy conditions will result in higher dunes (Ibid., p. 439). However, once the dune is formed, vegetation or fencing can be added to provide additional barriers to wind, to trap further sediment (O'Connell, 2008, cited in O'Donnell, 2016, p. 439). Studies suggest that a variety of fencing can be used, whether it is "snow fencing, plastic or fabric fencing, … [and] coniferous … or other brush can be used to create dunes provided that it does not completely block the wind" (O'Donnell, 2016, p. 439).

Beach nourishment and dune restoration and creation can help maintain the beach and dune ecosystems, have less environmental impact, and be more cost-effective compared to traditional hard infrastructure measures (Ibid., p. 445). However, beach and dune construction does not come without any impacts. Machinery and added sediment can alter existing ecosystems, and temporarily reduce water quality, and studies are still being done to identify the long-term effects of beach nourishment and impacts on areas dredged for sediment (Ibid., p. 445). Further, there is a risk that the public gains a distorted perception of what a natural shore should look like, potentially leading to poor coastal management decisions (Nordstrom, Lampe, and Vandemark, 2000, cited in O'Donnell, 2016, p. 445).

Beaches and dunes can also protect coasts from both waves and storm surge. Waves become unstable as they move on the slope of a beach, causing them to break and reducing their energy, and dunes can create a barrier to storm surge, while larger dunes can provide a windbreak (O'Donnell, 2016, p. 446). Although beaches and dunes can reduce damage from storms, their effectiveness depends on a number of factors, including beach width, dune heights (greater than 4 metres is recommended), building setbacks from the dune vegetation line (150-200 metres is recommended), and large restorative waves are needed for large dunes to form (Taylor et al., 2015, cited in O'Donnell, 2016, p. 446).

Beaches and dunes are able to adapt to sea level rise if sufficient sediment supply and migration is possible. If there is no room to migrate, the ecosystem can become too narrow to maintain the processes needed to establish vegetation, which ultimately affects the ability to adapt to sea level rise naturally (O'Donnell, 2016, p. 446).

Hybrid Approaches

Soft structural approaches can be combined with structural components, such as fiber logs, revetments, sills, breakwaters, oyster reefs, breakwaters, and other wave attenuation devices to help reinforce the living shoreline (O'Donnell, 2016, pp. 439-443).

To provide a better understanding of the application of these approaches, the following is a summary of different types of hybrid approaches, and the types of soft structural approach they can support.

Fiber Logs

Fiber coir logs are a biodegradable erosion control product that typically deteriorates in approximately three to five years, helping stabilize shores by allow sediment to collect on the landward side and vegetation establish (Ibid., p. 440). Coir logs can be placed in single or multiple rows, and must be anchored in the ground to prevent movement from tides and waves, and are better suited to low-energy wave settings (Ibid., p. 440).

Marsh Toe Revetments

As the name implies, this low profile structure is combined with marshes to help stabilize and prevent the erosion of marsh edges. It typically has a height that is approximately 0.3 metres above the mean high water level, slightly above the marsh level, while still allowing for tidal inundation through and above the structure (Ibid., p. 440). To further help maintain the marsh ecosystem, gaps are placed along the revetment to allow for tidal exchange (Ibid., p. 440).

Marsh Sill

A marsh sill is similar to a marsh toe revetment, but is a lower stone breakwater to protect the marsh edge, and is constructed at or near the mean high water level, and may include gaps for tidal exchange and habitat access (Ibid., pp. 440-441). Typically marsh sills are installed and backfilled with sediment, and planted with marsh vegetation to create a marsh fringe along eroding shores (Ibid., p. 440).

Marsh sills can also use oyster reefs via oyster bags or loose oyster shells, while also providing other ecological benefits by attracting oysters, which self maintain the reef. Oyster reefs are also known as living breakwaters, and provide habitats for other foraging species and help improve water quality through the removal of sediment and algae to help improve light transmission for submerged vegetation (Ibid., p. 441).

Breakwaters

Breakwaters are not generally considered living shorelines, although they can help support living shorelines, by helping sediment deposit into a stable pocket or crenulate shoreline beaches (Hsu et al., 2010 cited in O'Donnell, 2016, p. 441). Breakwaters are higher than marsh sills and can attenuate storm waves, however, will not prevent inundation (O'Donnell, 2016, p. 442).

Wave Attenuation Devices

Wave attenuation devices can help prevent erosion while also supporting benthic ecosystems, or help re-establish coral reefs, and sometimes are used in place of rock sills (Ibid., p. 442). Although these devices can also be used as hard structure breakwaters with the added benefit of providing habitat for marine species, more studies are needed to determine their effectiveness in providing coastal protection (Ibid., p. 442). An example of a wave attenuation device is a reef ball, which is designed to prevent erosion while also providing and supporting benthic habitats (Ibid., p. 443).

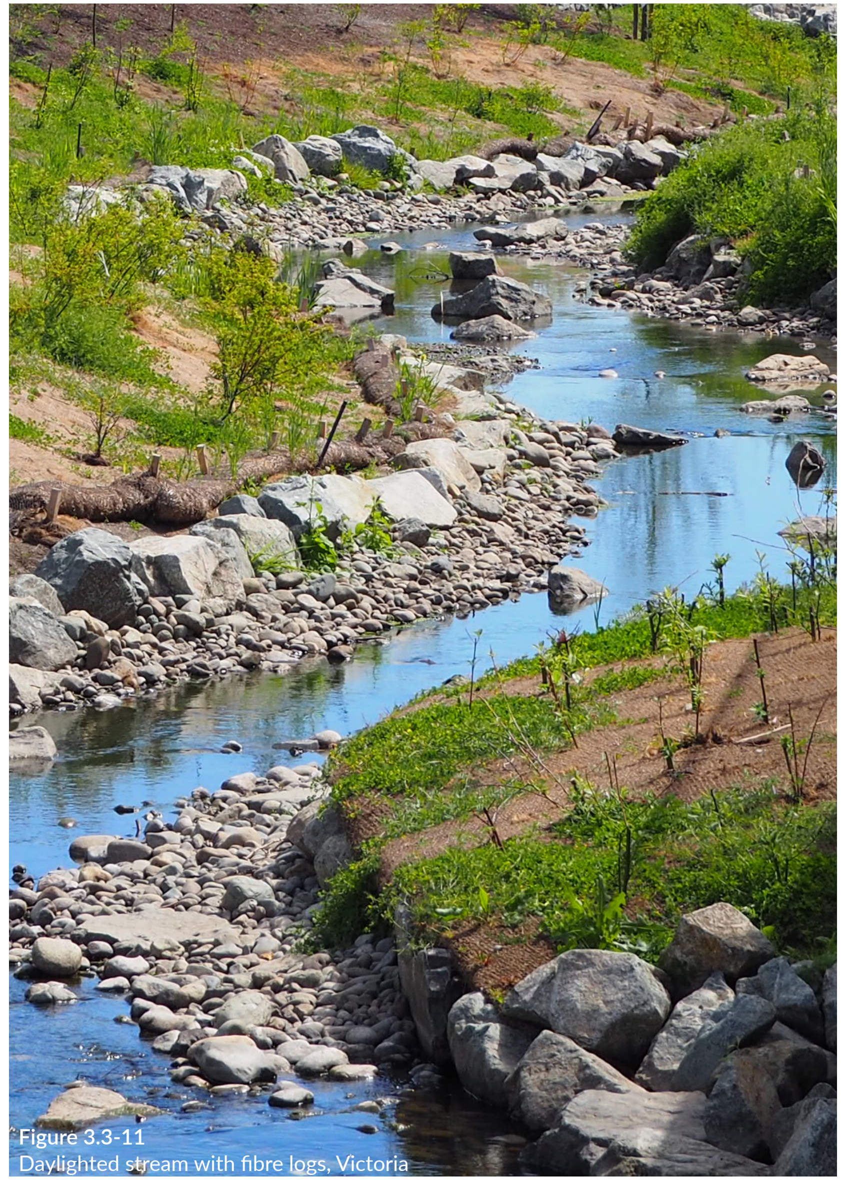

Figure 3.3-11
Daylighted stream with fibre logs, Victoria

Coastal Wetlands

Coastal wetlands form at the margins of continents or islands, and are a product of geomorphology, hydrology, disturbance agents and biotic feedbacks (Wolanski et al., p. 1). The variety of coastal wetlands derives from the physical processes that "facilitate and constrain the diversity of plants and animal[s]" (Ibid., pp. 1-2). Wolanski et al. (2009, p.2) define coastal wetlands as:

> "Ecosystems that are found within an elevation gradient that ranges between subtidal depths to which light penetrates to support photosynthesis of benthic plants and the landward wedge where the sea passes its hydrologic influence to groundwater and atmospheric processes. At the seaward margin, biofilms, benthic algae, and seagrasses are representative biotic components. At the landward margin, vegetation boundaries range from this located on groundwater seeps or fens in humid climates to relatively barren salt flats in arid climates."

Coastal wetlands include tidal flats, seagrasses, salt marshes, and mangroves; however, mangroves are limited to low and mid-latitudes where the temperature is a controlling factor and usually occur in areas that rarely experience frosts and have exposure to warm ocean climates (Ibid., p. 3). The type of coast can also restrict where wetlands occur, as wetlands will be minimal along cliffs and rocky shorelines (Ibid., p. 3).

Wetlands are continually evolving and shifting in time and space. During glacial periods when sea levels were lower and water was stored on continents, wetlands would have been restricted to continental margins much lower in elevation on the continental shelf than present day, and closer to the tropical areas (Ibid., p. 4). When sea level started to rise rapidly (in geological time) 20,000 years ago, wetlands went under a large disturbance as the glaciers in the polar and near polar regions melted, releasing land from the pressure of ice and resulting in the process of isostatic rebound, with land rising faster than the sea (Ibid., pp. 4-5). The rate of rebound has varied in different regions, with some areas reaching a steady state in relation to sea level, and other areas still going through the isostatic rebound process. In these areas, estuaries are still moving seaward as new land emerges (Ibid., p. 6). Coastal wetlands are continually responding to sea level and the accumulation of saline and freshwater sediment, influencing their ability to migrate, maintain their surface elevation, and their distribution (Ibid., p. 8).

Stabilization

When mudflats become exposed above sea level, the hydrodynamics start to change. As depressions start to form, they alter the movement of water, creating channels which then can start to erode the landward banks to form a tidal course (Ibid., p. 9). As the head of the tidal course continues to erode, tidal creeks extend over unvegetated mudflats, forming a dendritic pattern (Ibid., p. 10). Prior to a mudflat becoming vegetated, biofilms may stabilize the flats while bioturbation may destabilize them (Ibid., p. 10). Mudflats then become vegetated by pioneer species, which then change the patterns of erosion and sediment deposition (Ibid., p. 10). As the vegetation becomes established, roots stabilize the banks by reducing erosion from tidal currents and waves, and trap sediment brought in by the rising tide (Ibid., pp. 10-11).

Flooding and aeration regimes also influence coastal plant dynamics. Areas continually flooded support submerged aquatic vegetation (as long as there is sufficient transparency in the water column to permit photosynthesis), mud and sand flats are located in areas with intermittent flooding, intermittent aeration of roots zones supports wetlands, whereas areas seldomly exposed to saturated soils, such as uplands, are not influenced by sea level (Ibid., p. 14).

The most common disturbances along temperate coasts come from storms. Other than tsunamis and hurricanes, storm surges can threaten coastal communities due to the flood waves occurring over long timescales, which inhibit the ability of vegetation to attenuate the waves generated (Ibid., p. 15). If flood waters reach an eroded area, the saline water can kill freshwater vegetation, creating a bare, unprotected, area which can easily erode; however, this also allows tidal creeks to expand and grow in the freshwater floodplains (Ibid., p. 18).

Dead organic matter affects the evolution of a coastal wetland and support herbivores who feed on it and microbes that decompose it (Ibid., p. 20). Benthic fauna also consume plant litter and enable nutrient cycling; however, the distribution of benthic fauna is determined by sediment type, topography, and hydrology (Ibid., p. 20). In salt marshes, migratory birds may transport consumed biomass (e.g. Canada geese), and in areas where plant litter is not consumed, it might be exported in large racks of dead grass, which may accumulate on beaches during storms (Ibid., p. 21). Fish and crabs also consume biomass during high tide and facilitate the export during the ebb tide back toward the estuary (Ibid., p. 21).

Water depth, energy of waves, the rate of sea level rise, and salinity will also influence the type of coastal wetland ecosystems. The ability for light to transmit through water will influence tidal flats and seagrasses, and plants in the upper elevations are limited by the desiccation during low tide (Ibid., p. 22). Tidal amplitude will influence the distribution of emergent plants, where greater tidal amplitude provides a greater distribution range (Ibid., p. 22). Soil salinity is affected by climate and freshwater discharge, and wetlands respond to both sea level and sediment sources and exchanges (Ibid., p. 22). Suspended sediment affects seagrass and can temporarily affect the productivity of tidal flats; however, sediment accumulation helps wetlands maintain sea surface levels in relationship to sea level rise (Ibid., pp. 22-27).

Abiotic and biotic factors control the character of coastal wetlands. Abiotic factors include “tidal inundation, sea level, climate, groundwater, accommodation space (the upper space between sediment surface and tidal level), sediment supply, water quality, and water and sediment dynamics” (Pratolongo et al., p. 90). Plant communities on the landward side of coastal wetlands can vary depending on climate and groundwater, especially water quality and water level (Ibid., p. 90). In the intertidal zone, the primary control is the hydroperiod, the frequency, duration, and depth of tidal inundation (Ibid., p. 91). Coastal wetlands in humid regions that are in close proximity to high tide often have a "high degree of waterlogging and organic matter accumulation" and the type and density of salt marsh vegetation will determine the accretion and stabilization of sediment (Ibid., p.91).

For salt marshes and tidal flats that have a ramp profile, the elevation in relation to the tidal range and hydroperiod will control the distribution of plants and animals (Ibid., p. 91). The amount of sediment available will determine the deposition rates within a salt marsh, while lower elevations in a tidal flat will accumulate more sediment on each tide (Ibid., p. 92). Tidal velocity, rainfall, and biological activity also influence the amount of sediment suspended in water (Ibid., p. 92). Sediment accretion in the ramp profile relates to elevation and hydroperiod. As the hydroperiod decreases with elevation and a salt marsh is more exposed to freshwater drainage and the upper portion of the intertidal zone "switches from incremental minerogenic sediment accretion to the accumulation of organic matter in situ" (Ibid., p. 92). Within this upper salt marsh zone, freshwater will support less salt-tolerant vegetation, such that "aerobic decomposition may become more important" for sediment accretion (Ibid., p. 92).

For salt marshes and tidal flats within a 'creek' model, the drainage channels in the marsh capture the water from the flood tide, and only when the tide exceeds the capacity of the creeks, the tide will spill on the rest of the marsh, resulting in a larger sediment grain size near the creek margin (Ibid., p. 94). Sediment accretion rates for ramp versus creek profiles occur over different timescales - "the ramp model accounts for widespread and gradual trends in vertical accretion, the creek model is focused more on the local scale and potentially rapid development of three-dimensional sedimentary features" (Ibid., p. 94).

Patterns of Vegetation

Pioneer species, such as *Salicornia*, *Suaeda*, *Aster*, and *Spartina* are typically found in the lower extents of salt marshes that are regularly inundated with salt water (Ibid., p. 95). In this zone, "substrate stability, oxygenation, and sulfide toxicity are key factors controlling plant establishment" rather than salinity, due to the constant tidal flushing (Ibid., p. 95). In the mid-level zone, where there is less inundation, plants are more diverse; however, salinity can be a limiting factor, concentrating in this zone due to "prolonged periods between tidal inundation and when evaporation takes place" (Ibid., p. 95). Biotic interactions and salt pans also tend to influence the establishment of plants in the high marsh zone; as salt concentrates in depressions where tidal flushing does not occur regularly, plant dieback can occur and shallow bare depressions may form (Ibid., p. 95).

Ecological Development

As temperate coastal wetlands are a product of both living and nonliving factors, they are principally influenced by allogenic factors, including sea level and salinity, and secondly by vegetation (Ibid., p. 96). Coastal wetlands in along the "Pacific coast of North America are less extensive due to the morphology of the shoreline, and the tidal regime is different from the Atlantic coast, with a more pronounced mixed tide, which likely influences low and high tide marsh distribution" (Ibid., p. 103).

Climate and Sea Level Change

There are some studies that indicate marshes can maintain surface elevation in relation to sea level rise when "allochthonous sediment show significant excess of vertical sediment accretion"; however, in deltaic regions, there is a greater risk of subsidence, which further increases the risks associated with sea level rise (Ibid., p. 110). Additionally, there is a risk that erosion along salt marshes could mobilize contaminants in previously stabilized soils (Ibid., pp. 110-111).

3.4 Transformative Approach

Aesthetic Performance

The strategies identified in the previous section illustrate some of the ways that cities can become more resilient to climate change, whether retreating from flood-prone areas and restoring natural processes, constructing landform features to divert flood waters, or making space and designing with water to reduce flood damage potential. However, taking into consideration the three lenses to approach resiliency, it is also important to consider how people perceive and understand flood risk related to climate change and how landscape design can support a transformative approach to coastal resilience. Theories related to aesthetic performance are particularly relevant to the transformative approach when considering how the design of our built environment can inform perceptions about climate change and flooding.

In *Sustaining Beauty. The performance of appearance*, Meyer (2008) describes how beauty and aesthetics can support sustainability when considering the performative aspects of designed landscapes. Meyer (2008, p. 6) identifies that the discussion of beauty is often dismissed in the discourse of landscape design in relation to sustainable design, although, this could also extend to the discourse of resilient design. However, according to Meyer (2008), aesthetic performance has the ability to invoke action in making people more adaptive to change in that experiencing landscapes has the ability provoke thoughts and wonder about the world around us and has the ability to shift our perception of what beauty is and what it means to us. As Meyer (2008, p. 18) notes, experiences are the vehicles for connecting with our environment, a connection that can shape our environmental ethic, and inform how we live our lives and the decisions we make to protect the environment.

Landscape architecture can facilitate experiences through design, by bringing awareness to the beauty of a place and passively educating the inner workings of a landscape, its connection to the larger environment, and how it responds to the larger systems acting upon it. Landscape design is also a cultural artifact, embedded within it are ideas and values, and in many ways inherently communicating ideas and values to people. Communication may be through what is being prioritized or emphasized in design, intentionally including or excluding specific features, and whether or not there is an intent to let people know how a landscape functions, the infrastructure supporting it, or how it connects to the cultural and natural systems that surround it. Design can also help shift perceptions of what people consider to be beautiful. Although designers should be sensitive to 'the translation problem' in relation to contextual beauty (Herrington, 2016, pp. 444-445), perceptions about beauty may shift as people become more aware of how a landscape functions, the ecological services it provides, and how humans can help or hinder the success of a landscape through how we design cities. Knowing this, designers can actively contribute to resilience by exposing people to different forms and conceptions of beauty and providing opportunities for people to connect with the landscape to promote an awareness of how the built environment responds to, and can transition with, climate change. Designers can also provoke thoughts on how we can live more in tune with the changing conditions that will be brought on by global warming, so that we are better equipped to adapt and be more resilient to the impacts we will face.

The reclamation of False Creek Flats severed its connection to coastal processes and the tidal waters that had made it a rich and diverse ecosystem, that was inherently resilient to shifting conditions. The absence of this history in False Creek Flats contributes to a public perception that the status quo is sufficient. It is clear the City of Vancouver is taking measures to address and minimize flood risks in the False Creek Flats through tools such as building codes that require elevated flood construction levels and rainwater management strategies to address stormwater. However, more can be done to help people understand the impacts sea level rise and climate change will have in the area. There are some areas along False Creek that help visualize the risk of sea level rise. For example, the artwork *'A False Creek,'* designed by Rhonda Weppler and Trevor Mahovsky, which illustrates the impact sea level rise will have in Vancouver. As one walks along the seawall in False Creek and sees the gradient of blue bands on the Cambie Street bridge, you begin to think about the banks of False Creek being underwater and how the landscape will change dramatically. The aesthetic

Figure 3.4-1
Sea level rise public art on Cambie Bridge, Vancouver

Figure 3.4-2
Terraced walkway, False Creek

Figure 3.4-3
Marking High Tide, David Lam Park

Figure 3.4-4
Habitat Island, False Creek

performance of this expression of sea level rise decentres your thoughts and makes you think about the larger systems at play, and shifts the perspective of climate change as something happening on a global scale, to something that is more personal. Other examples that provoke thoughts about changing water levels are also found along the edge of False Creek, including Habitat Island near Olympic Village, with the large stepping stones that lead to the island during high tide; and the terraced walkways on the north shore of False Creek that hint at making pathways still accessible during high water events. These spaces communicate the spatial and temporal interplay of the shifting shorelines and how we use public space.

A transformative approach that considers beauty within the landscape and the performative aspects it provides can make the public and False Creek Flats more resilient to flooding. Creating opportunities for people to engage with the landscape can also help shift priorities in how the area will undergo redevelopment. Interventions that emphasize the priority of managing water to address flooding may raise awareness of the inherent risks of living in a coastal landscape, while also strengthen peoples connection and care for the environment. A more informed public can also make Vancouver more resilient through a better understanding of the implications of climate change and supporting policy decisions the City of Vancouver needs to make in order to take action to tackle climate change.

Imageability and Legibility

The legibility of a city can contribute to aesthetic performance as well as resilience. The structure of a place facilitates a mental image in people's minds, which can help people understand their surroundings, while also providing a sense of uniqueness and a sense of place. The structure of a place contributes to its imageability, what Kevin Lynch (1960, pp. 8-9) describes as:

> "... that quality in a physical object which gives it a high probability of evoking a strong image in any given observer. It is that shape, color, or arrangement which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment. It might also be called legibility, or perhaps visibility in a heightened sense, where objects are not only able to be seen, but are presented sharply and intensely to the senses."

To understand the imageability of a place, Lynch (1960, pp. 46-83) identifies five elements that relate to the structure and pattern of a city, which include its landmarks, nodes, edges, paths, and districts. A summary of each of the elements is noted below.

Landmarks tend to have spatial prominence within a given setting and can serve as a point of reference (Ibid., p.78). They are different from districts, in that the observer does not perceive mentally entering a landmark; instead, they are external objects that stand out from their surroundings (Ibid., p. 48). Landmarks can be seen from a distance, serving as radial references, or only within specific local contexts when they are visible only within a certain proximity or spatial position in relation to the landmark (Ibid., p. 48). Landmarks also tend to have more value if an observer is aware of its historical association or has attached meaning to the object (Ibid., pp. 81).

Nodes tend to be the places where paths intersect, or the places that have an "intensive foci" for which an observer travels to and from (Ibid., p. 47). Lynch identifies that nodes can also be the "condensation of some use or physical character, [such] as a street-corner hangout or an enclosed square" (Ibid., p. 47).

Edges tend to be the boundaries or the linear breaks between two areas and can include "shores, railroad cuts, edges of development, [and] walls" (Ibid., p. 47). Lynch (1960, p. 47) describes that edges can act as barriers, that prevent movement, or can also be the seams that intersect and join two regions together.

Paths are the "channels" that the observer moves along, which include walkways, streets, transit or rail lines, and or even canals, in some cities (Ibid., p. 47). As Lynch (1960, p. 47) notes, paths are important elements for people's mental image, as people "observe the city while moving through it, and along ... paths ... other environmental elements are arranged and related." Paths also have a directional quality, and once one becomes more familiar with a path, it may also have continuity from features its adjacent to, such as building edges (Ibid., p. 52).

Districts are areas of the city that have a distinct quality in which an observer perceives as having mentally entered (Ibid., p. 47). Districts tend to be characterized by a common element, which could include land use, built form, color, sounds, materiality or other forms of landscape or architectural patterns. Districts also tend to serve as exterior reference points (Ibid., p. 47) Lynch identifies that the physical characteristics of a district are based on thematic continuity, which can include multiple varieties and combinations of “texture, space, form, detail, symbol, building type, use, activity, inhabitants, degree of maintenance, [and] topography” (Ibid., p. 67).

Through the concept of imageability, the built environment can enhance the aesthetic experiences of a place by creating legibility of the urban structure of an area, which can help people better understand their surroundings. When people are uncertain of their surroundings, this can cause discomfort and disorientation. In consideration of climate change and flood risks that the False Creek Flats will face in the future, the lack of good urban form could create more stress during flood events if people are unable to know how they can escape.

An awareness of the how the landscape relates to its surroundings can also increase the resilience for people that live, work, or visit the False Creek Flats. Making room for the water and creating new edges and paths for people to engage with the water can facilitate a better understanding of the dynamic tidal landscape, while also creates a sense of place within Vancouver. False Creek Flats has a unique history and context within the city that could enhance peoples experience within it and should be celebrated. In consideration of the City of Vancouver’s desire to make False Creek Flats a creative centre and an employment hub, it needs to be a place that people want to live, visit, or work. If the False Creek Flats lacks the ability to creating a memorable image in people’s minds, to give it a positive sense of place, this could detract from the city’s goals and the success of attracting investment.

An understanding of the pattern and structure of the False Creek Flats can help identify areas that should be reinforced or reconfigured to strengthen its imageability. Strengthening the imageability of False Creek Flats can also facilitate the transformative approach in relation to resiliency, through design decisions that emphasize certain elements, related to the paths, edges, nodes, districts, and landmarks, which can serve to help support the shift to thinking about how we live and build with water.

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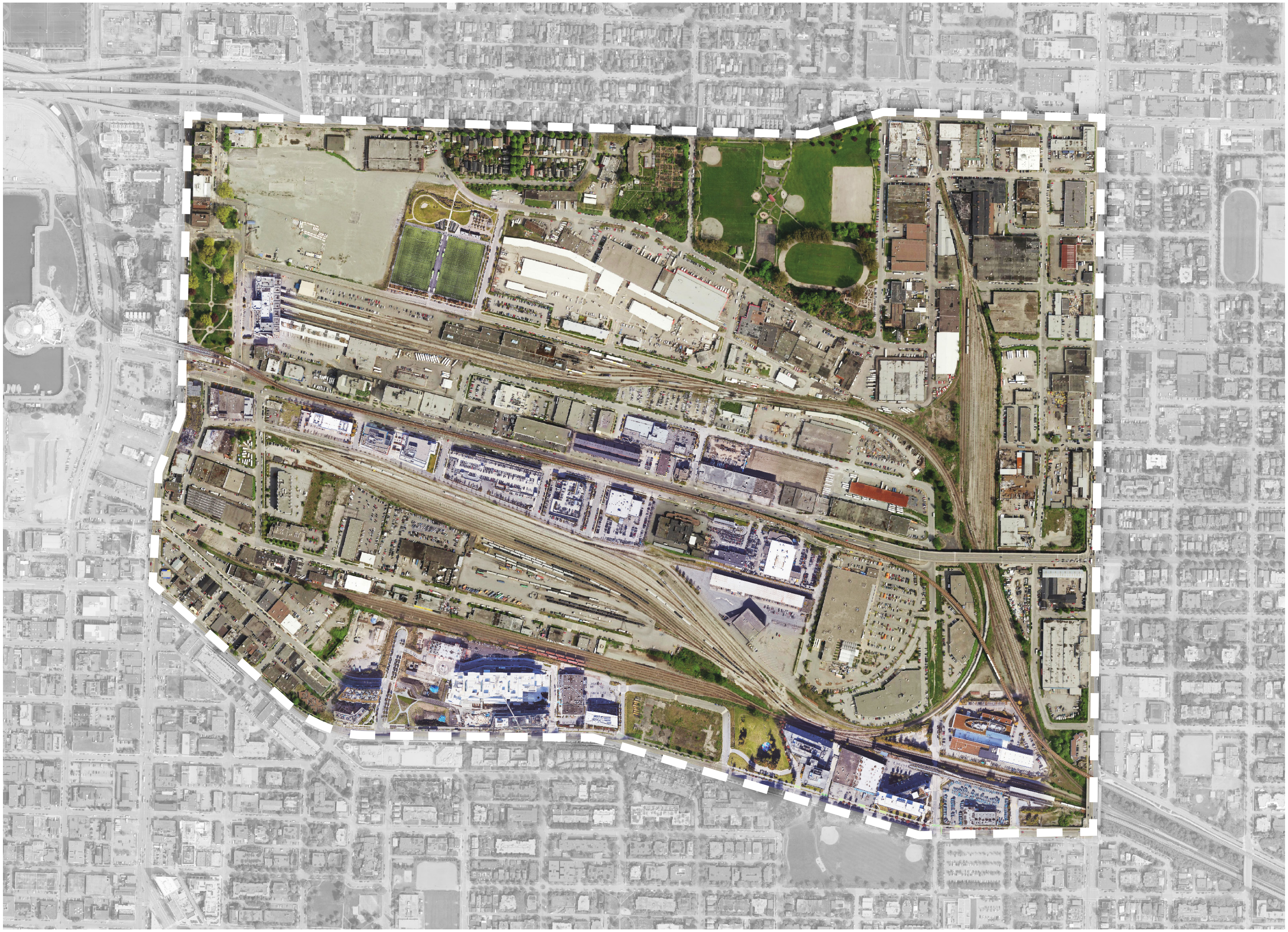


Chapter 4
A Design Strategy for False Creek Flats

4.1 Image of False Creek Flats

- Landmarks
- Nodes
- Edges
- Paths
- Districts

4.2 Design Strategy

- Design Strategy
- Building Resilience
- Reconstructing the Water Network
- Building Resilience
- Reconstructing the Water Network
- Retreat / Protect / Adapt in the False Creek Flats
- Design Scheme
- New Structure of the False Creek Flats
- Landscape Shift

4.3 Managing Stormwater

- Proposed Topography
- New Surface Drainage Pattern

4.4 Integrating Low Impact Development

- Terminal Avenue and Vancouver Flea Market
- Low Impact Development Small Street
- Low Impact Development Destination Street
- Low Impact Development Industrial Street
- Low Impact Development Campus Mall

4.5 Emergence of a Coastal Wetland

- Shifting Shorelines and Landscape
- Plant Zones and Water Levels

4.6 Cultivating Opportunities to Connect with the Landscape

- Tidal Flat Park
- Pacific Central Station Park
- Mountaineer Station Park and Plaza
- Boxcar Habitat Island

Figure 4.0-1
Extent of False Creek Flats

4.1 Image of False Creek Flats

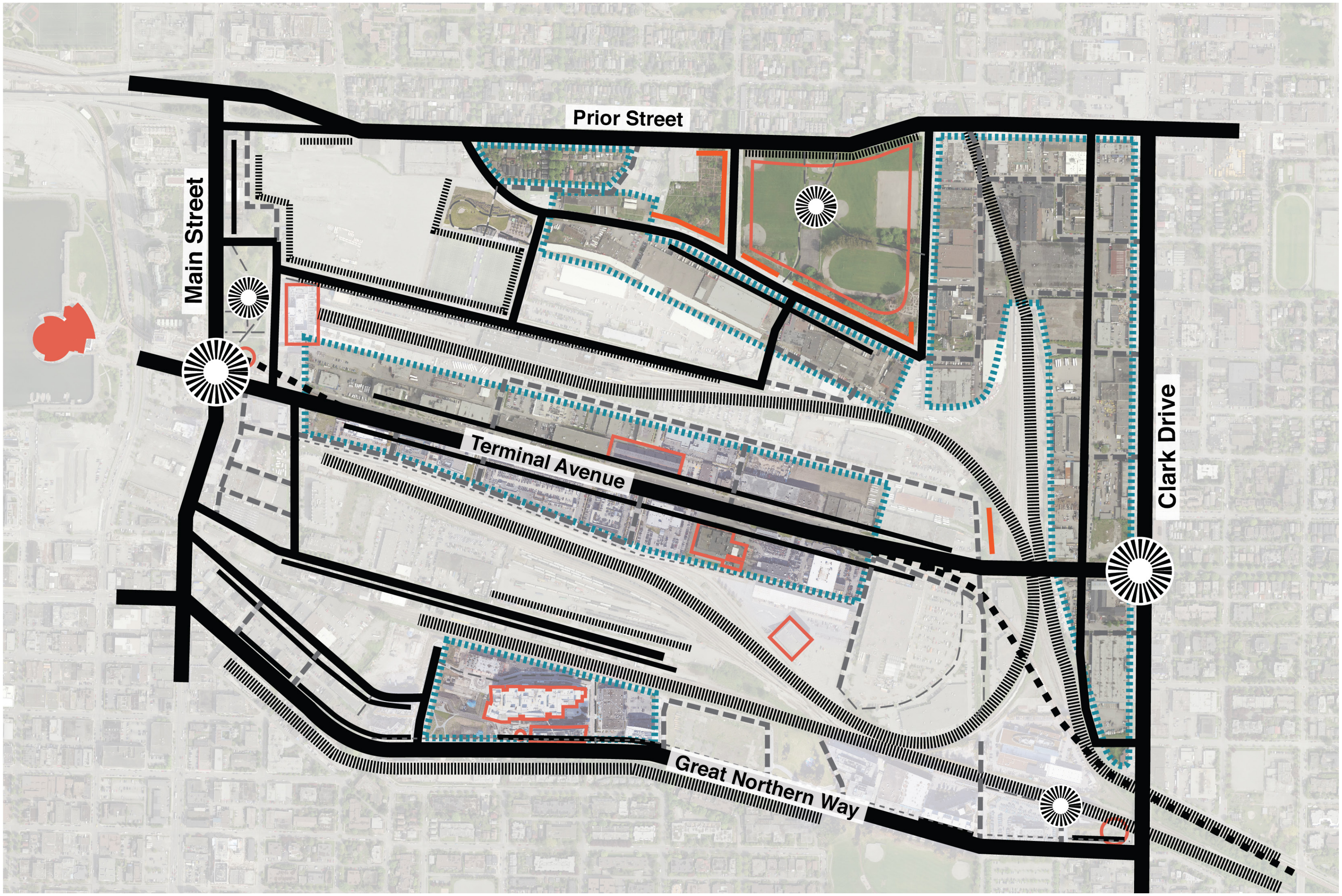


Image of False Creek

The first five subsections explore the structure of False Creek Flats, in relation to the features identified by Kevin Lynch in Image of the City (2006). Identifying the landmarks, nodes, edges, paths, and districts will begin to reveal the structure and legibility of the site. Typically this process of mapping is done through interviews with people familiar with the site and who are able to illustrate their own cognitive maps. The following maps, however, are based on the authors own site visits to the False Creek Flats in the summer of 2016 and the fall of 2018.

Figure 4.1-1
Image of the City Structure of False Creek Flats

Landmarks

Some critical landmarks in the False Creek Flats help provide mental markers as one moves through the site. When traveling through the site, these landmarks quickly let someone know where they are, where they need to go, and stood out either because of the aesthetic of the architecture, color, or contrast to their surroundings. For example, Pacific Central Station was a key landmark indicating an arrival to the site. It also has the typical grandeur of a central train station architecturally representative of its time.

The flea market is a distinct landmark and hard to miss with its burnt red colored facades with giant white lettering. It also has a few historical pictures and a mural on its walls, hinting at the vintage nature of the market inside its walls. A landmark that is newer to the area is Emily Carr University. The colorful windows give it visual uniqueness, and it appears to be the heart of the digital campus on Great Northern Way.

The East Van cross is symbolic of the east side of Vancouver, a culturally diverse and eclectic neighbourhood. The City of Vancouver commissioned this public art piece titled Monument for East Vancouver in 2009 by Ken Lum, and is located at East 6th Ave (extension of Great Northern Way) and Clark Drive. The siting of the monument is somewhat awkwardly pointing inwards to False Creek Flats, and a bit difficult to see straight on.

The Canadian Packers Storage Building and smokestack stand out in contrast to their surroundings, mainly due to the dark exterior brick cladding, and physical mass of the building. The building is considered to be representative of the “industrial streamline Modern style” and thought of as having “set the standard for the large utilitarian buildings” of its time (Vancouver Heritage Foundation).

The smokestack is also visible from areas outside of the False Creek Flats, and there is a direct view to the stack from 6th Ave and Prince Albert Street above the escarpment south of Great Northern Way.

Strathcona Park could be considered a landmark. It is an ample green space that punctuates Prior Street on the north side of False Creek Flats and contrasts the industrial hardscape of the Flats.

The Rocky Mountaineer Station also stands out; however, this might be due to its isolation from other buildings within the area and the sea of parking that surrounds it. A historic locomotive repair shed for the Canadian Northern Railway; the building now serves as a station for the Rocky Mountaineer that provides train service to Calgary, Banff, and Jasper.

Science World is the terminus of Terminal Avenue. Although it is outside of the False Creek Flats, it is the furthest west marker of the site and can be seen along Terminal Avenue, especially when traveling on the Grandview viaduct.

The North Shore Mountains also act as a landmark for False Creek Flats and the city. Due to the flat topography of the False Creek Flats and the relatively low building heights, the mountains are highly visible throughout the site.

Figure 4.1-2
Landmarks, False Creek Flats

Figure 4.1-3 Monument for East Vancouver, Clark Drive and East 6th Ave

Figure 4.1-6 Vancouver Flea Market, Terminal Avenue

Figure 4.1-7 Thornton Park

Figure 4.1-4 Canada Packers building on Terminal Avenue

Figure 4.1-5 Rocky Mountaineer Station

Figure 4.1-8 Emily Carr University

Figure 4.1-9 Pacific Central Train Station

Nodes

Some of the distinct nodes in False Creek Flats include the intersection of Main Street and Terminal Avenue. This intersection feels like the gateway into False Creek Flats and is also the location of the World of Science train station. Thornton Park, next to the train station, is another node that serves as a gathering space for many of the locals in the neighbourhood.

Another larger node includes the intersection of Clark Drive and Terminal Avenue, which is another major entry/exit point into False Creek Flats. This node is also elevated in comparison to the rest of the site, and provides excellent views to the city center, the mountains and the warehouse area within the Flats.

Strathcona Park also serves as a node; it is a gathering space for recreational activities, including baseball, track, tennis, skateboarding, and play structures for children. Another smaller node is the VCC Clark train station, which is currently the terminus of the Millennium line. This line will soon be expanding west with a stop proposed at Emily Carr University.

Figure 4.1-10 Terminal Avenue and Main Street

Figure 4.1-11 Clark Street and Terminal Ave

Figure 4.1-12 Strathcona Park

Figure 4.1-13 Thornton Park

Figure 4.1-14 Looking west - Terminal Ave from the Grandview Viaduct

Legend

Minor Node

Major Node

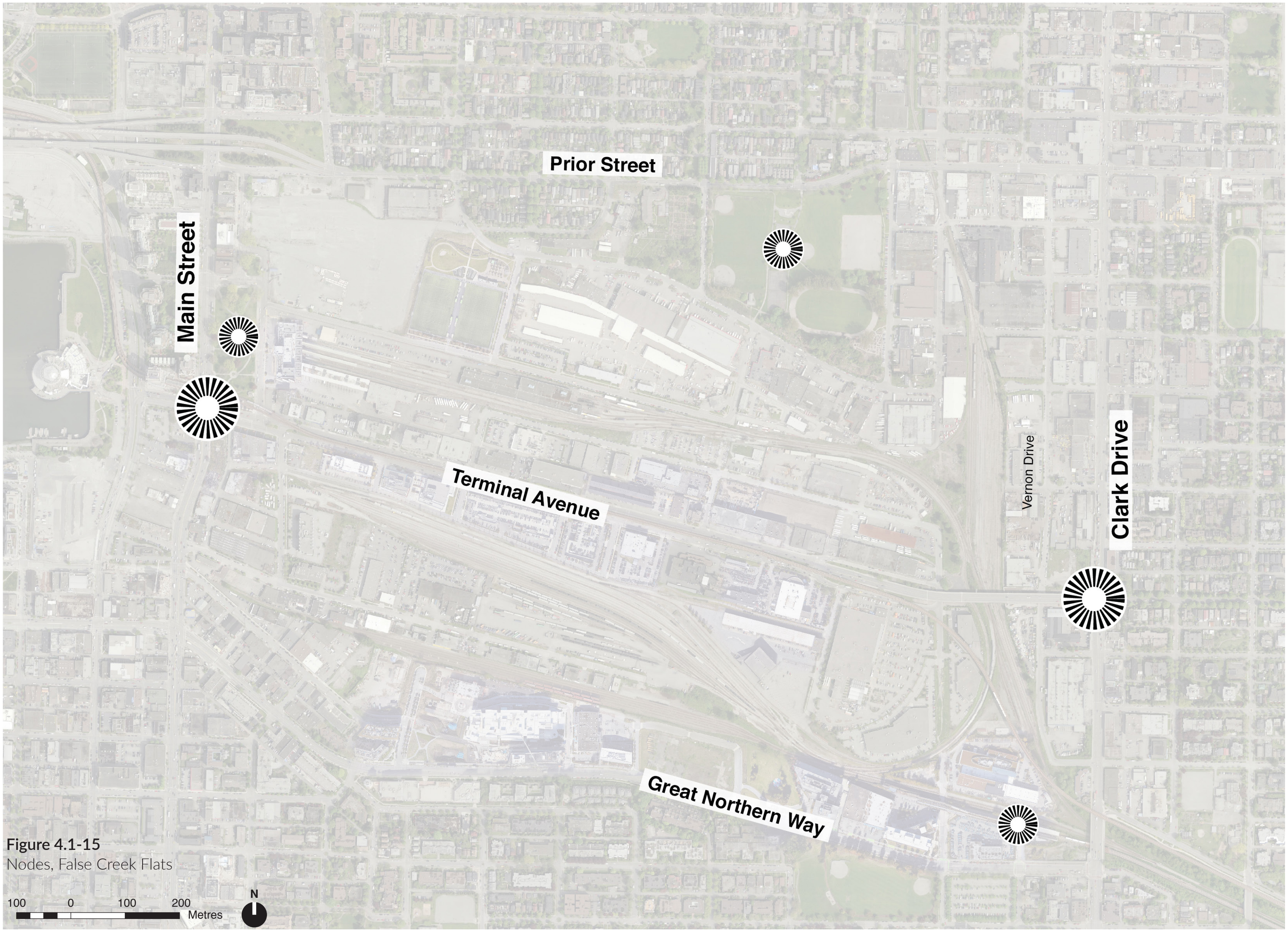


Figure 4.1-15
Nodes, False Creek Flats

Edges

The dissection of the site with the rail prohibits circulation throughout False Creek Flats, furthering the feeling of being kept out and closed off with the chain link fences that run along some properties. Some of the fences include barbed wire to prevent trespassers. Along Strathcona Park and the Strathcona Community Garden, there is a distinct edge of vegetation. The edge along the community garden is so thick you might not even know there is a community garden if you were not familiar with the area.

The escarpment on the south side of Great Northern Way, which includes residential developments lining the street, creates a wall and sense of enclosure. The hill is only accessible at certain points, including a stairway leading up into Mount Pleasant at East 6th Avenue and Prince Albert Street. The historic buildings at the northeast edge of Main Street also form a distinct edge. While walking along Main Street, these buildings create a wall that keeps your focus on the street; however, the volume of traffic makes for an unpleasant experience.

Figure 4.1-16 Skytrain along Terminal Avenue

Figure 4.1-17 Rail yards north of the Grandview Viaduct

Figure 4.1-18 Entrance into Strathcona Community Garden

Figure 4.1-19 Typical chain link fencing along sidewalks

Figure 4.1-20 Main Street looking south

Legend

- Vegetation Edge
- Skytrain / Viaduct
- Street wall
- Fencing
- Rail / Escarpment

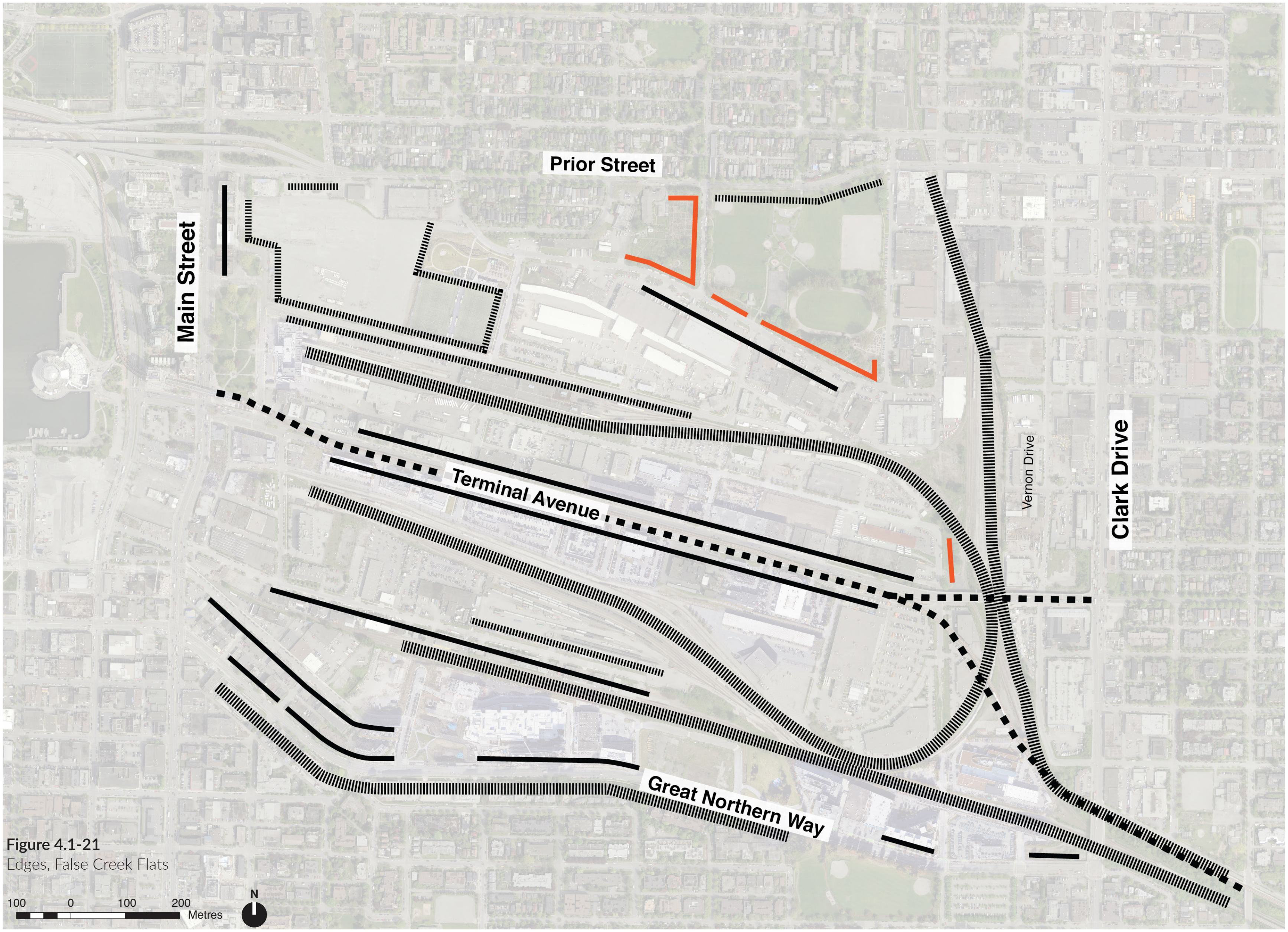


Figure 4.1-21
Edges, False Creek Flats

Paths

The main paths in False Creek Flats are Prior Street, Main Street, Clark Drive, Great Northern Way, and Terminal Avenue. These are the primary roads that enclose and move through the site. They are also high volume roadways that create an uncomfortable pedestrian experience. Although the Grandview Viaduct provides interesting city views, it brings a significant amount of traffic through False Creek Flats from the drivers looking to avoid the rail crossing at Prior Street.

Unfamiliarity with the area makes it confusing to travel through the site, not knowing if you will hit a dead end. Rail infrastructure dissects the site at multiple points and these areas are not passable by vehicles or pedestrians. There are a few paths dedicated to pedestrians such as the barricaded path on National Avenue and the multi-use trail along the Pacific Central rail yard. However, the overall pedestrian experience in False Creek Flats is lacking in connectivity, quality, and design, and contributes to an unappealing image of the area.

Figure 4.1-22 Pathway on National Avenue facing east

Figure 4.1-23 Prior Street, next to Strathcona Park

Figure 4.1-24 Multi-use trail along CP rail yard facing west

Figure 4.1-25 Terminal Avenue facing west

Figure 4.1-26 Multi-use trail on Great Northern Way

Legend

- Pedestrian pathway
- Multi-use Trail
- Local roadway
- Collector roadway
- Arterial roadway

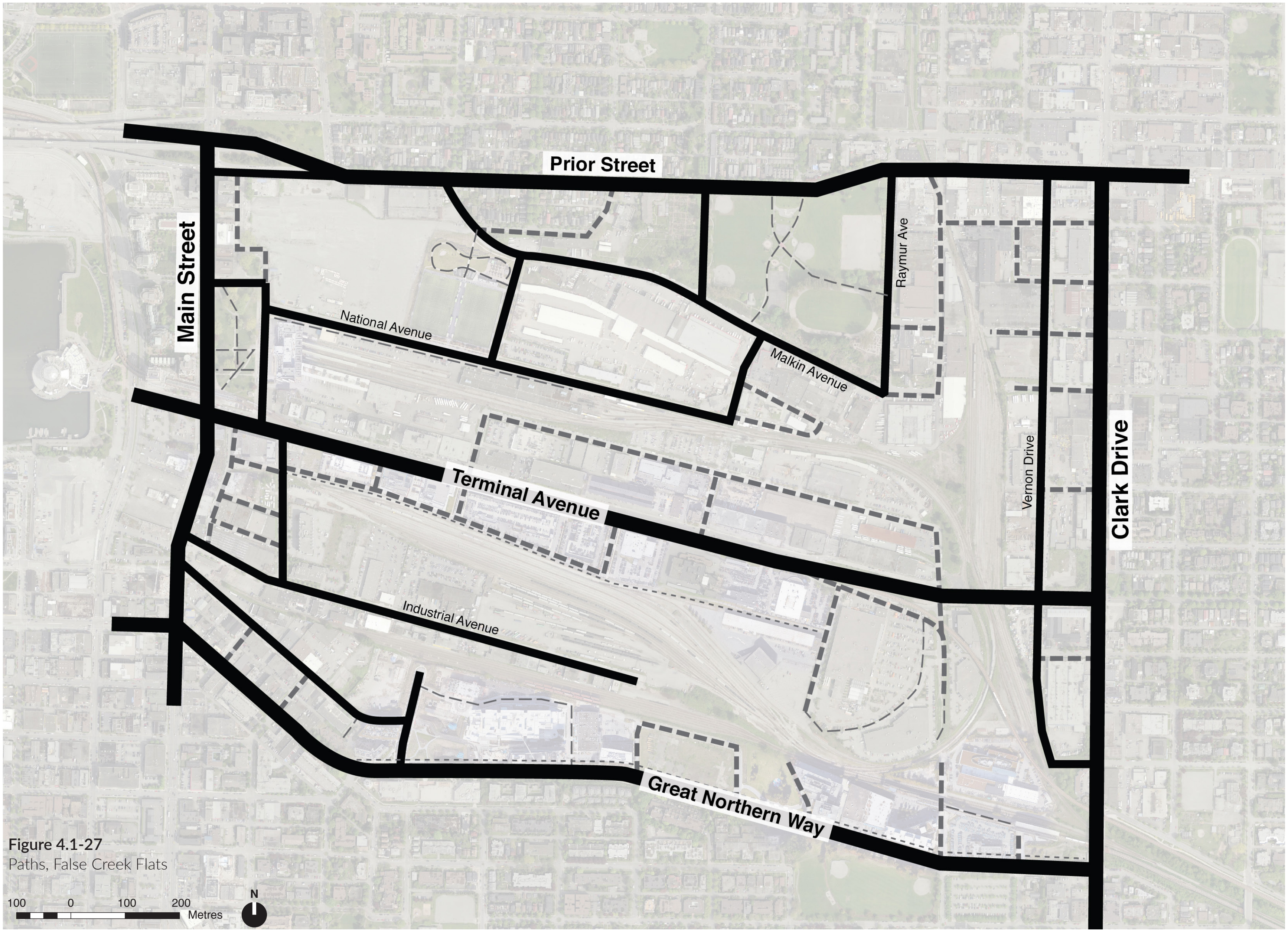


Figure 4.1-27
Paths, False Creek Flats

Districts

Some districts within False Creek Flats give you a sense of feeling you have entered a 'new' area. These districts have a particular character either based on the type of buildings, land use activities, or even the sounds from within the space, such as the vehicular noise from the nearby roadways.

Residential enclave
There is a small section of low-density housing on the south side of Prior Street that slopes inward towards False Creek Flats.

Food Hub
A row of food distribution companies creates a distinct presence along Malkin Avenue. Supporting the connection to food production is the Strathcona Community Garden to the north, the small community garden in Trillium Park, as well as the community garden at the southeast corner of Strathcona Park.

Warehouse District
The large box-shaped warehouses define this area along Glen Drive and Vernon Drive. With no sidewalks and large trucks moving through the district, it is not pedestrian friendly. The outdoor storage yards also make the area look unappealing.

Terminal Spine
Terminal Spine is the name used in the City of Vancouver's False Creek Flats Plan. It is the armature of the Flats and is lined with commercial and institutional development, although somewhat haphazardly with views truncated by the elevated Skytrain. Terminal Avenue is also a major thoroughfare that takes people from Clark Drive to Main Street.

Creative Campus
Creative Campus is also a name used in the City of Vancouver's False Creek Flats Plan. It is a fitting name as the area contains both the Emily Carr University and BCIT, design and technology learning centers that will graduate the next generation of innovators.

Figure 4.1-28 Centre for Digital Media


Figure 4.1-29 Emily Carr University and Equinox Gallery

Figure 4.1-30 British Columbia Institute of Technology

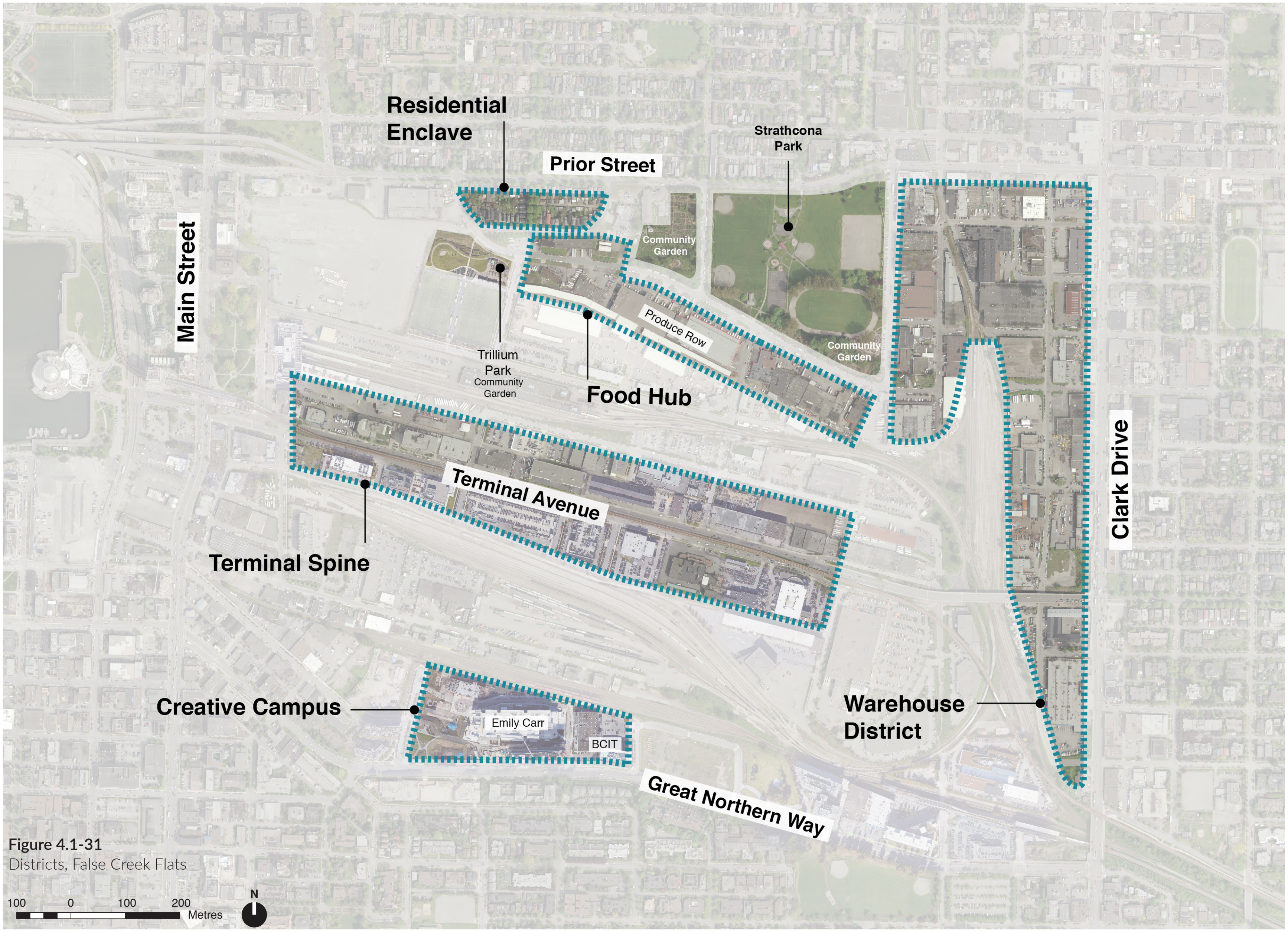


Figure 4.1-31
Districts, False Creek Flats

Figure 4.1-32 Strathcona Community Garden

Figure 4.1-35 Residential enclave

Figure 4.1-36 Strathcona Community Garden Path

Figure 4.1-33 Trillium Community Garden

Figure 4.1-34 Trillium Park and Community Garden

Figure 4.1-37 Trillium Park soccer fields

Figure 4.1-38 Warehouse area

Figure 4.1-39 Produce row, Malkin Avenue

Figure 4.1-40 The Produce Terminal, Malkin Avenue

Figure 4.1-42 View of warehouse area along Vernon Drive from the Grandview Viaduct looking north.

Figure 4.1-41 West on the north side of Terminal Avenue

Figure 4.1-43 West on the south side of Terminal Avenue

4.2 Design Strategy

Design Strategy

The proposed design is grounded in reintroducing coastal processes to the site, which will re-engage the public with the historical ecology of the site, build a connection to the coastal landscape, provide ecological services by making room for coastal habitat, make the area resilient to sea level rise, and improve stormwater management.

False Creek Flats is not only prone to flooding, it is also approaching the capacity of its storm sewer network. Creating room for both sea level rise and stormwater will take pressure off of the city's stormwater infrastructure by creating flood storage above ground. Green infrastructure will also improve the water quality by filtering contaminants before it reaches the coastal waters, creating a healthier habitat for marine ecosystems.

As sea level continues to rise, coastal habitats creep further landward; however, the development of Vancouver's coast leaves little room for habitat, causing the 'coastal squeeze' effect. Creating more space for the water will also create more habitat for coastal flora and fauna, including migratory birds passing through Vancouver along the Pacific Flyway.

Adapting the landscape to make room for water will also emphasize a prioritization of addressing sea level rise, by not keeping water out, but finding ways to live with it. While creating more interaction with coastal processes will allow for passive education, it is also essential to incorporate beauty. Creating beautiful public places will not only enhance people's experience with the landscape, it can also have a performative impact. Landscape architecture can enable experiences, provoke the senses, communicate meaning, and provide respite and pleasure. Loved landscapes are well cared for and ensuring that the reintroduction of the coastal landscape is maintained and cared for, requires a design that will enhance people's experience with it and understanding of it. A better understanding of the coastal processes will also make people more resilient to the risks of living on the coast.

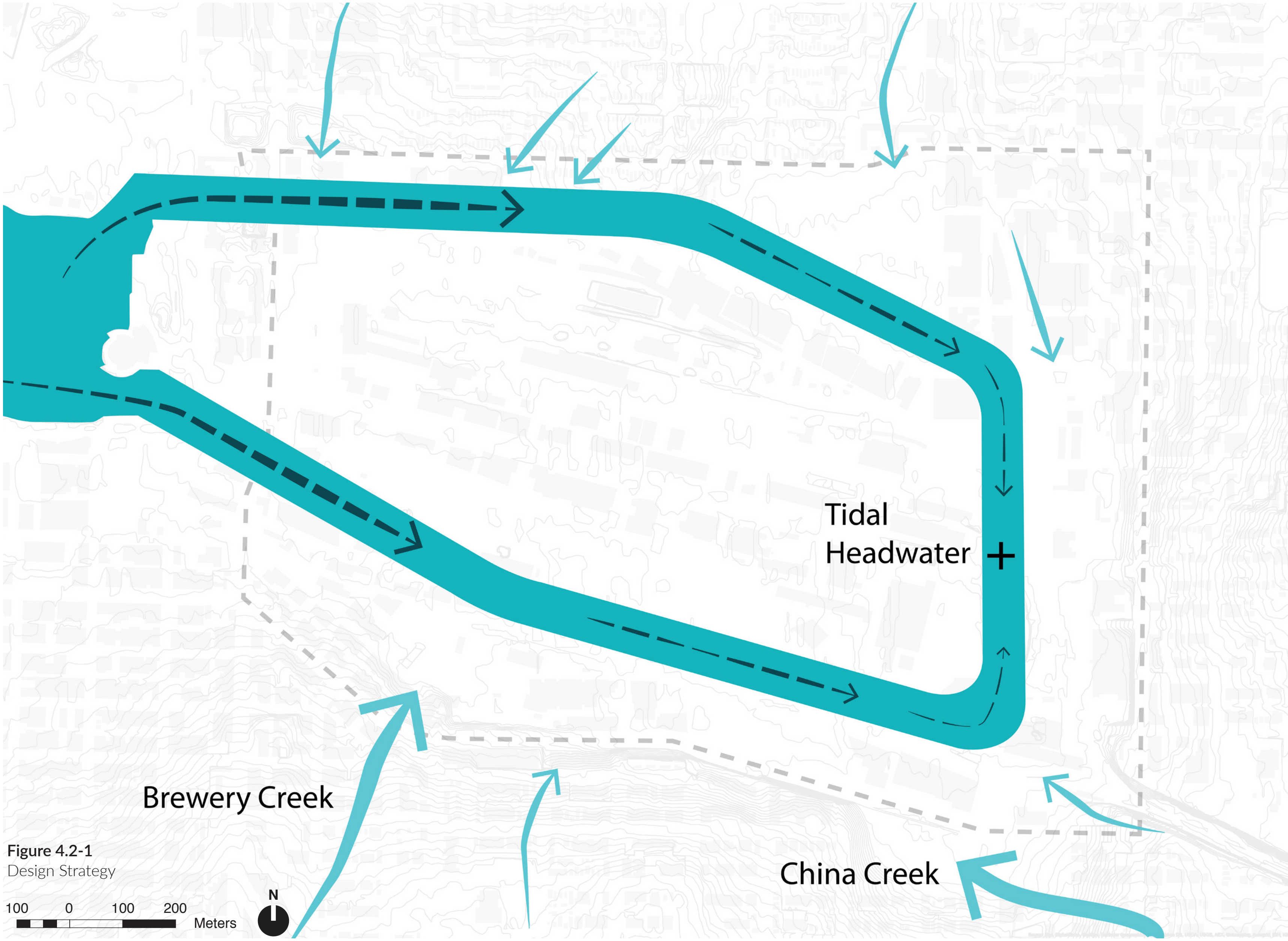


Figure 4.2-1
Design Strategy

Building Resilience

Increasing False Creek Flats' resiliency to sea level rise means developed areas need to be raised to remove potential flood damage. However, the areas requiring raising are substantial. Excavating land for the tidal channel will make room for the water, and the excavated material can also be used to raise the land to be adapted and redeveloped.

Due to the industrial activities that occurred on the False Creek Flats over the last century, excavating the fill that exist in the Flats will expose tidal water to potential contaminants, so both the wetland areas and the newly raised lands will need to be capped, to ensure that the pollutants can remain contained. Afterward, the channel can be filled to build the coastal wetland landscape — a potential source for the fill is the sediment dredged from the Fraser River. The Maplewood Marine Restoration project also used sediment from the Fraser River to restore a tidal flat in the Burrard Inlet.

As False Creek Flats is built on landfill it poses risks for buildings in the event of an earthquake. New development can minimize the damage potential by ensuring proper foundations, such as the use of piles that extend down to bedrock.

Additionally, the tidal channel will contribute to the area's stormwater management while also becoming habitat for flora and fauna. A constant supply of fresh water into the channel also supports water conditions for salmon habitat. Salmon are anadromous, meaning they travel to freshwater to spawn but live most of their lives in saltwater. Global warming is also affecting the temperatures of rivers, which is impacting the salmon that spawn in these waters. Creating opportunities for freshwater habitats in the False Creek Flats can provide room for salmon, and reintroduce culturally valuable fish back to this area. The freshwater habitats can be further enhanced by daylighting streams that once fed the Flats, such as China Creek and Brewery Creek.

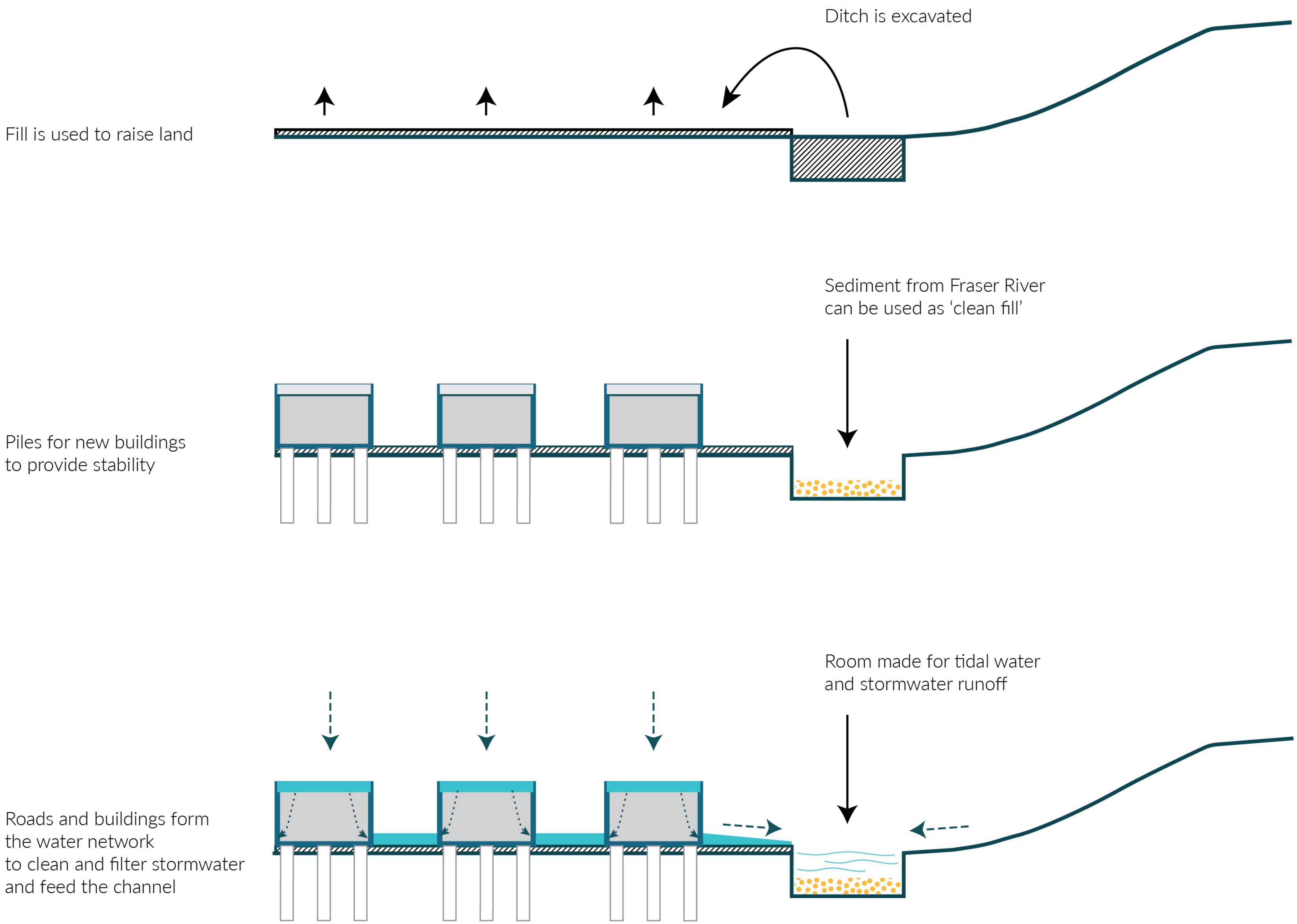


Figure 4.2-2 Building Resilience

Reconstructing the Water Network

Consideration of the coastal habitat means thinking about the buildings, roads, and public spaces all being part of the landscape and ultimately the water network. Emphasizing stormwater management for streets and buildings can facilitate innovative ways to 'live' with water, and help strengthen the human and non-human connection. Integrating a low impact development ethic also adjusts the thinking of the built environment and how it works with and is part of the landscape and environmental processes.

Low impact development can also enhance the livability of the districts by incorporating green infrastructure that can also reduce the urban heat island effect, and can create beauty, variety, and diversity in the everyday environment.

Industrial activity on the False Creek Flats has contaminated the land over time. As such, water is discouraged from being absorbed into the areas to be raised with landfill. Therefore, green infrastructure above the landfilled areas will have to convey water 'above' ground and direct it to the constructed coastal wetland. This approach to managing stormwater will ensure contaminants in the landfilled areas remain contained.

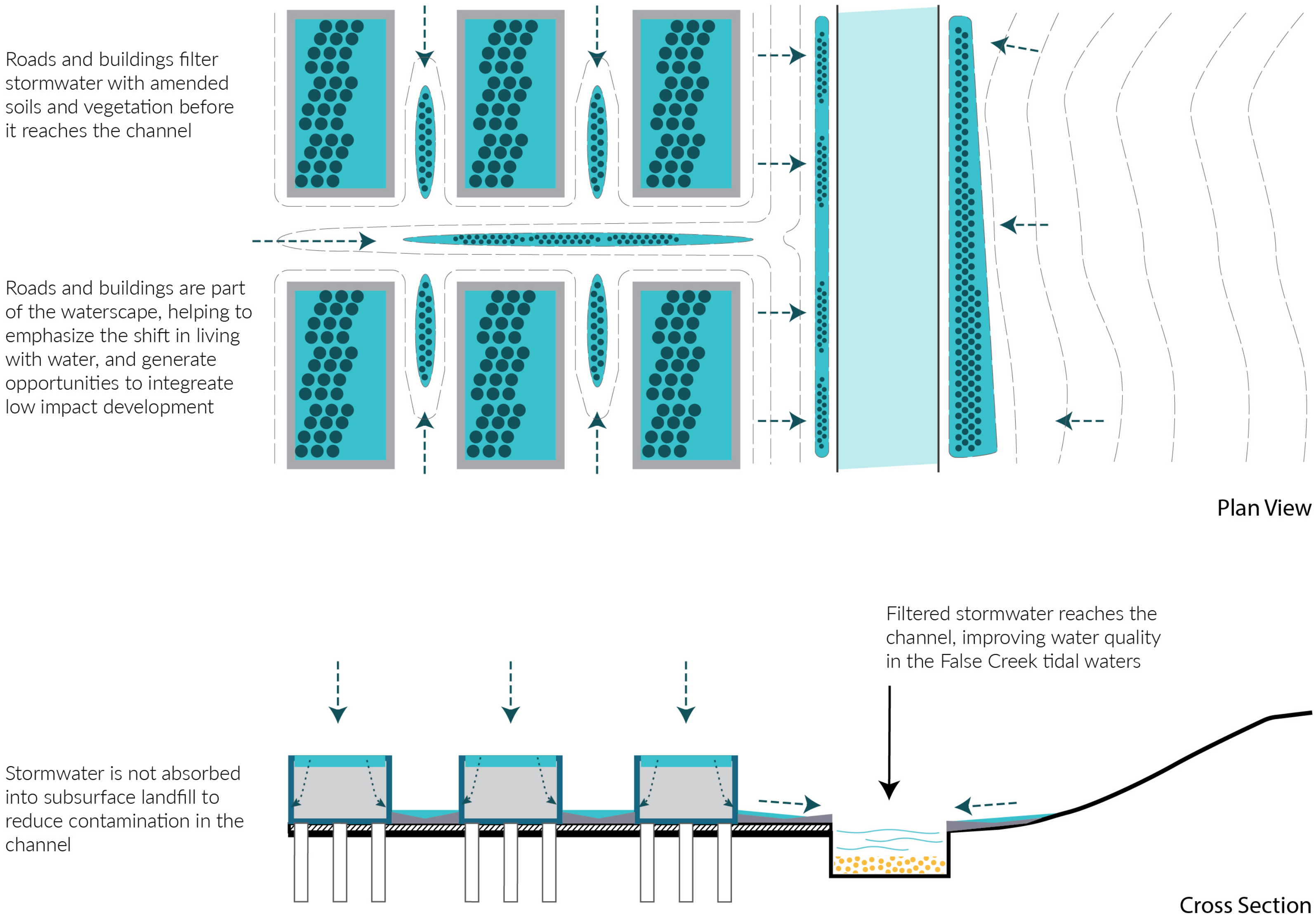


Figure 4.2-3 Reconstructing the Water Network

Retreat / Protect / Adapt in the False Creek Flats

Managed retreat is proposed in areas where redevelopment has not taken place, areas currently used for rail lines and storage, and older industrial sites.

Areas to be 'protected' include:

- Newer developments, such as the Emily Carr Campus area
- Residential areas (on East 1st Ave and on Atlantic Street)
- The newer mixed-use development (Citygate) west of Main Street
- Older development on the northeast side of Main Street, south of Prior Street, and
- Portions of the rail yard and lines that are used by the ports on the Burrard Inlet

The warehouse area is located on a slope that moves upwards to Clark Drive and is located outside of the floodplain.

Even though these areas are marked as 'protected,' it is proposed that they will incorporate green infrastructure to offset climate change impacts and to ensure stormwater is filtered before it enters the coastal water network.

Areas to be 'adapted' include districts within the floodplain which will be raised to reduce flood damage risks; however, these areas will be integrated with the waterscape, and some areas will allow for intermittent flooding during extreme high tides and intense storms.

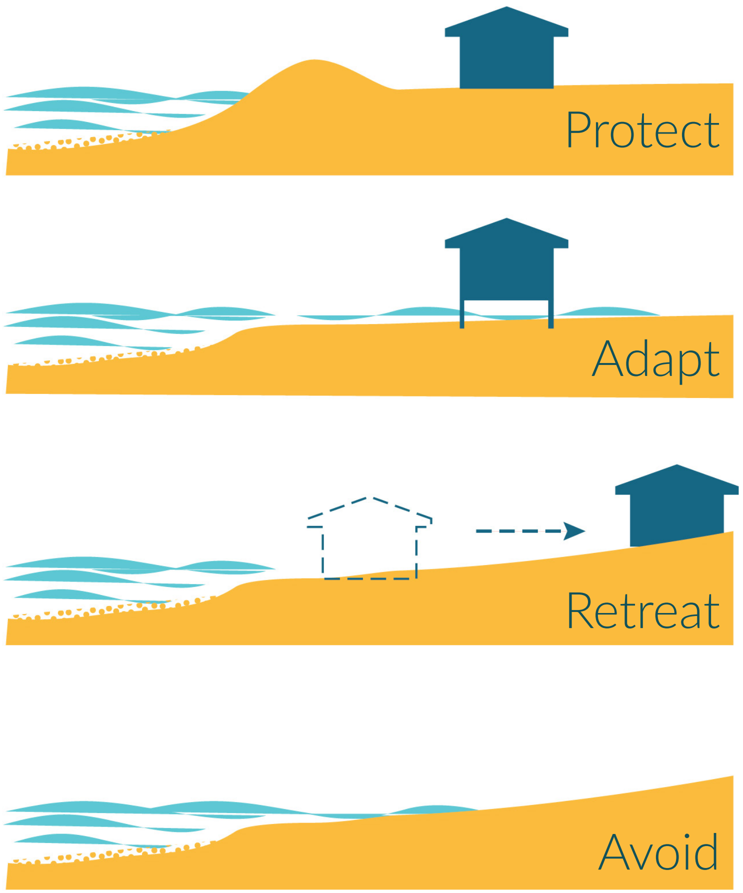


Figure 4.2-4
Strategies for Sea Level Rise

The areas designated to be protected, adapted, or retreated in this schematic consider the landmarks, nodes, paths, edges, and districts of the site, and the case studies reviewed that provide examples of approaches to manage flood risks associated with climate change.

In this schematic, the 'avoid' approach is integrated with the 'retreat' approach, in that development will mostly avoid existing open or vacant lands.

Figure 4.2-5
Retreat, Protect, Adapt in False Creek Flats

100 0 100 200 Meters

N

Design Scheme

- Waterway makes room for sea level rise and stormwater runoff
- Material excavated from the waterway builds up redeveloped areas in the Food Hub, Terminal Spine and parts of the Creative Campus
- Green and open space provide pedestrian circulation and connectivity throughout False Creek Flats
- Green space entry points connect to Brewery Creek and China Creek
- Road connection and realignment of Malik Avenue to Clark Drive to help reduce the volume of traffic on Terminal Avenue
- A landform berm along the rail line that leads to the port lands, to prevent flooding of the rail line
- Block widths based on Vancouver blocks surrounding False Creek Flats, to strengthen the street wall edge while allowing for more permeability throughout False Creek Flats
- Relocation of the Trillium Park soccer fields outside of the floodplain to Strathcona Park
- The redevelopment of the Vancouver Flea Market and incorporating public space around the building to create additional market and public space opportunities
- Introduction of a tidal flat park in the area between Main Street, Prior Street, and the Central Pacific station.
- Water connection points to False Creek are proposed by the World of Science and the Northeast False Creek Flats

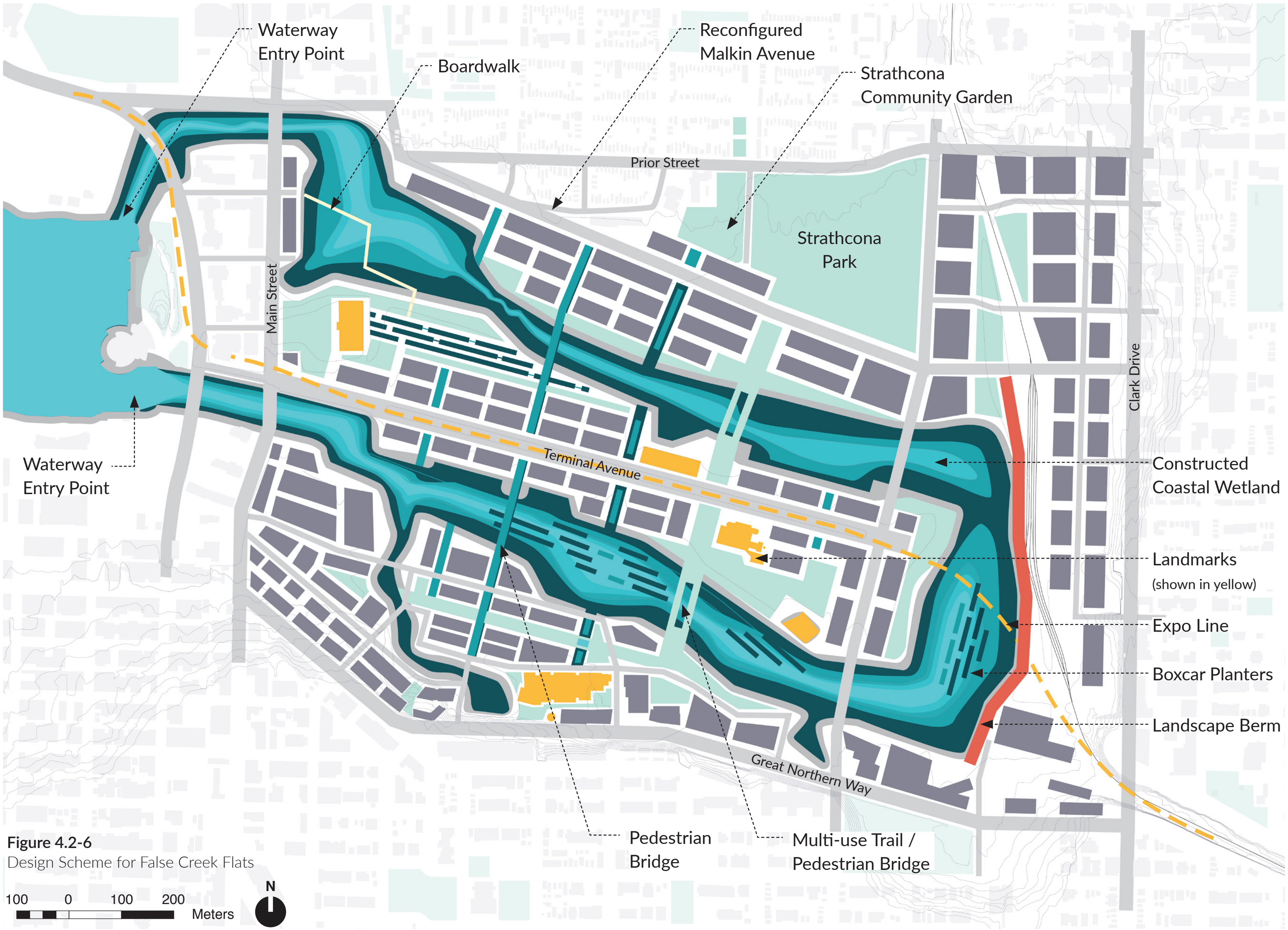


Figure 4.2-6
Design Scheme for False Creek Flats

Landscape Shift Relationship to Sea Level Rise

Coastal wetlands are dynamic systems that change over time based on environmental conditions and human activities. The structure of a coastal wetland is informed by:

- Geographic location, as it relates to temperature and exposure to winds and other environmental conditions;
- Geomorphology, including soils, isostatic rebound, and subsidence; and
- The hydrology of the site, including water from rivers, streams or drainage from upland areas, the presence of groundwater, salinity, sea level rise, and tidal range.

Coastal processes and the gradient of the wetland facilitate and constrain the diversity of plants and animals within the wetland.

To encourage a variety of coastal habitats in the False Creek Flats will require sensitivity to the slope and drainage of the landscape and its relationship to the tidal range. As sea level continues to rise, the coastal wetland will continue to increase on the landward side of the water to the extent of the high tides. Acknowledging the forces that influence the variety of coastal wetlands can also provide a variety of experiences for the public to enjoy as well as passive education opportunities. The landscape could be designed to visualize the transition of the coastal landscape over time in response to the shift in the tidal water regime.

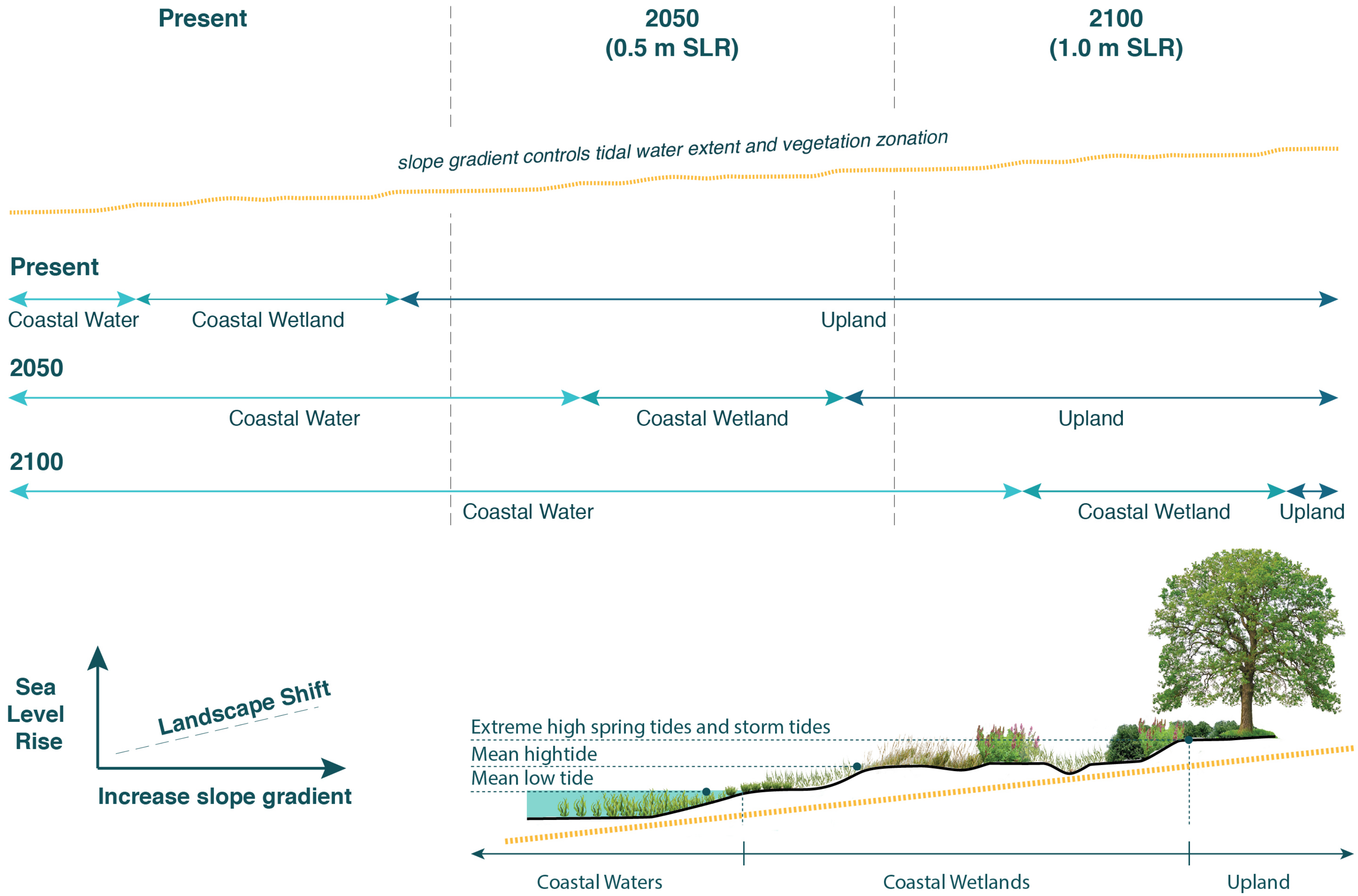


Figure 4.2-7
Landscape Shift Relationship to Sea Level Rise

4.3 Managing Stormwater

Proposed Topography

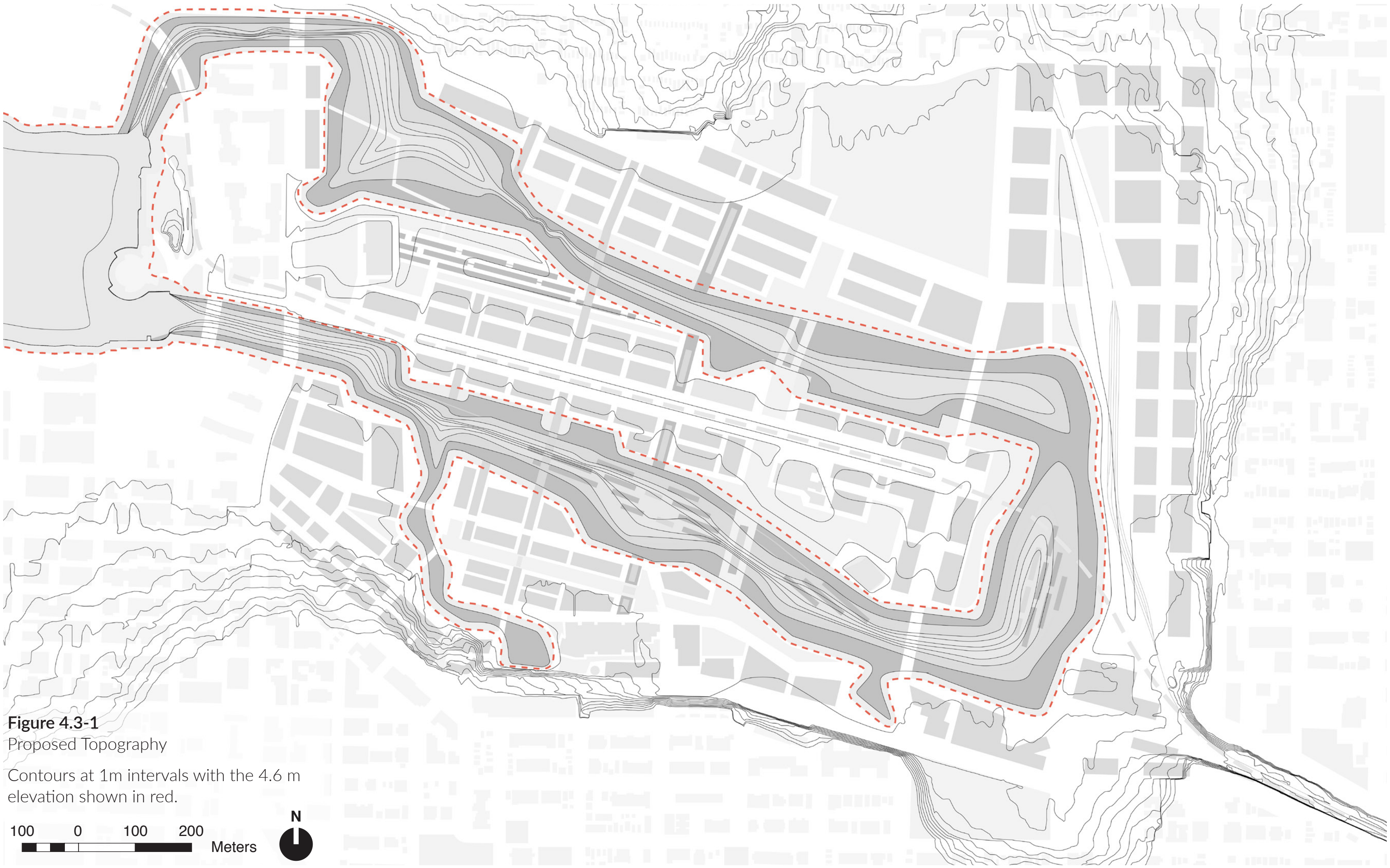


Figure 4.3-1
Proposed Topography

Contours at 1m intervals with the 4.6 m elevation shown in red.

Proposed Surface Drainage

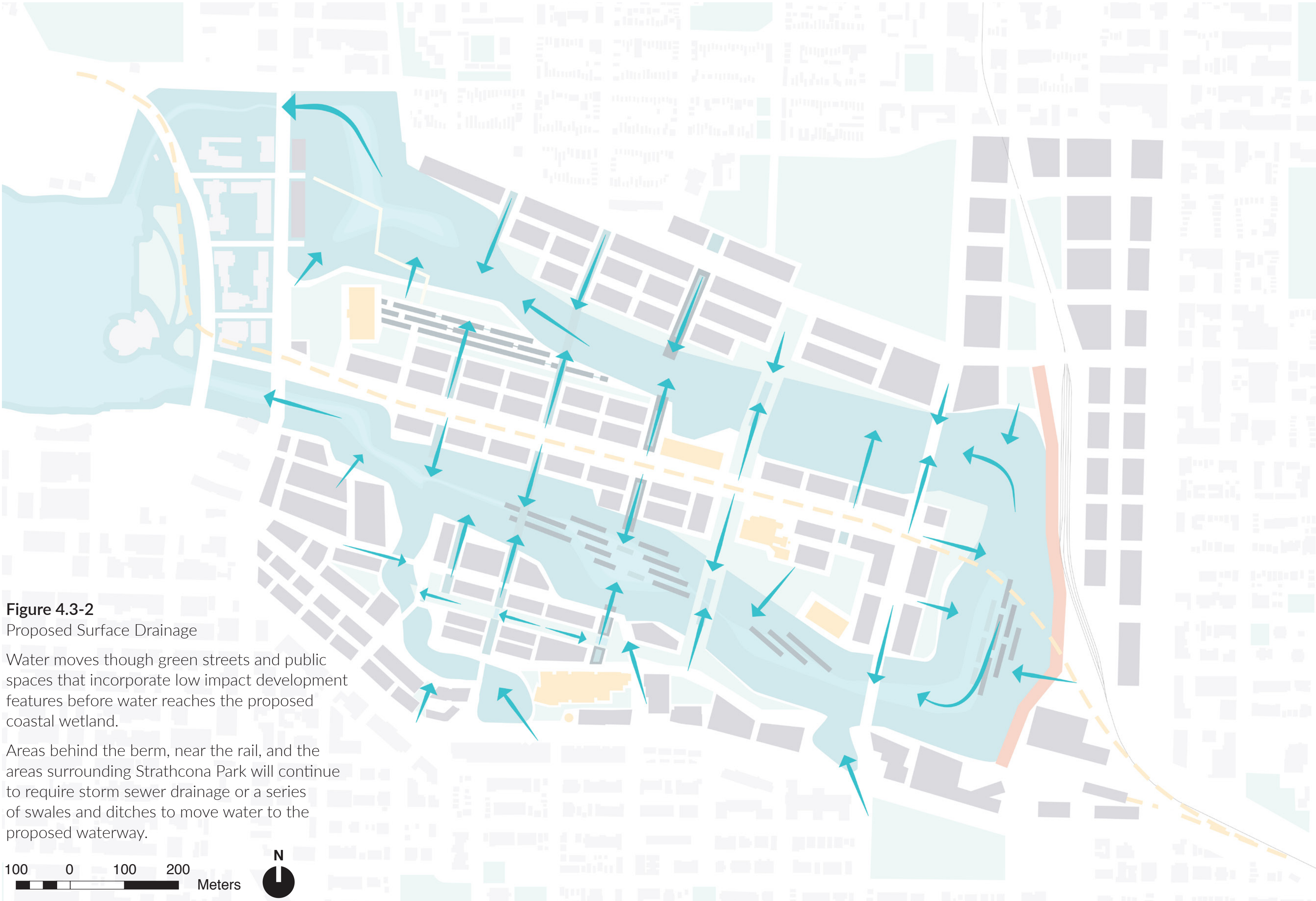
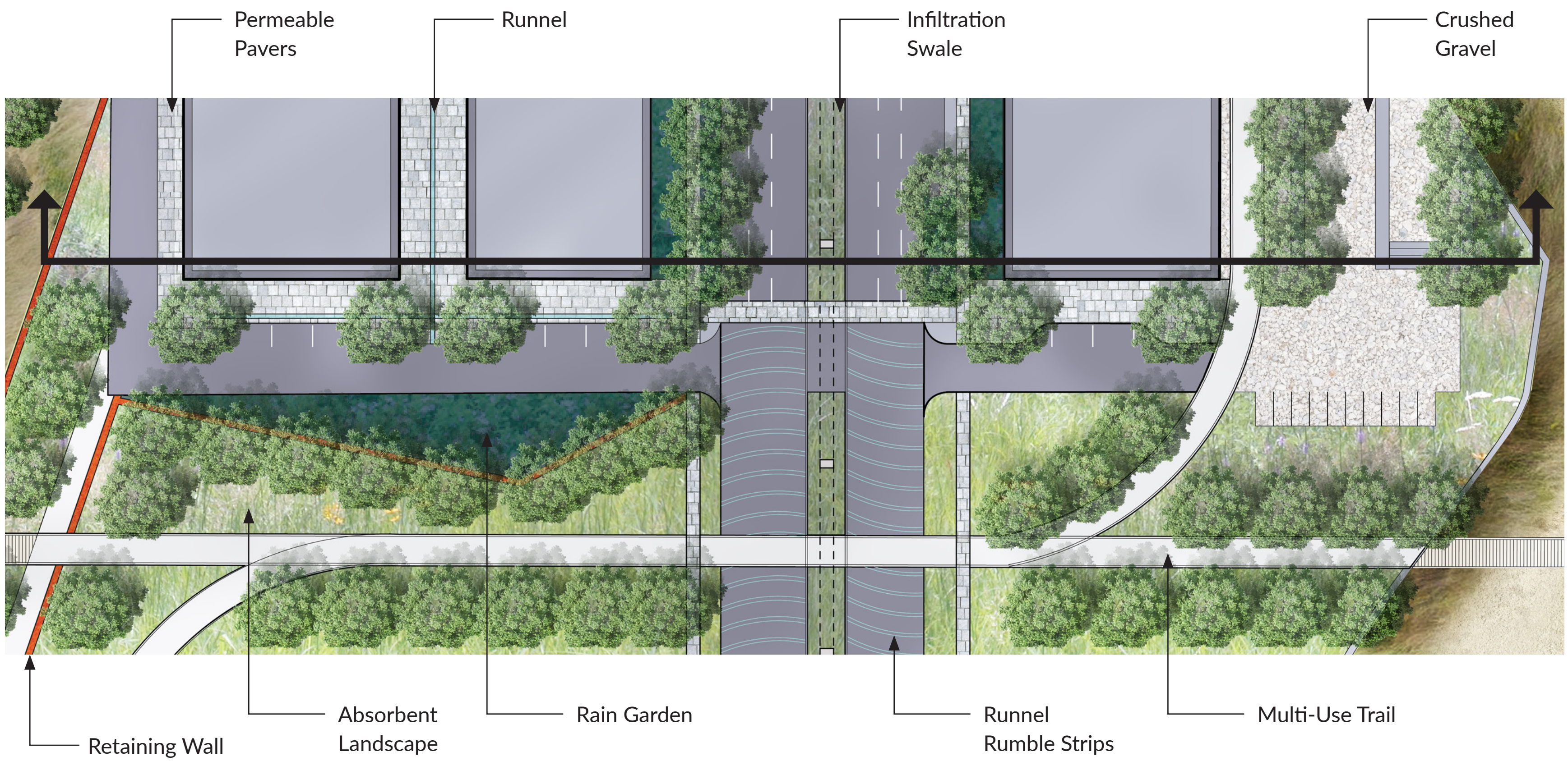


Figure 4.3-2
Proposed Surface Drainage

Water moves though green streets and public spaces that incorporate low impact development features before water reaches the proposed coastal wetland.

Areas behind the berm, near the rail, and the areas surrounding Strathcona Park will continue to require storm sewer drainage or a series of swales and ditches to move water to the proposed waterway.

4.4 Integrating Low Impact Development



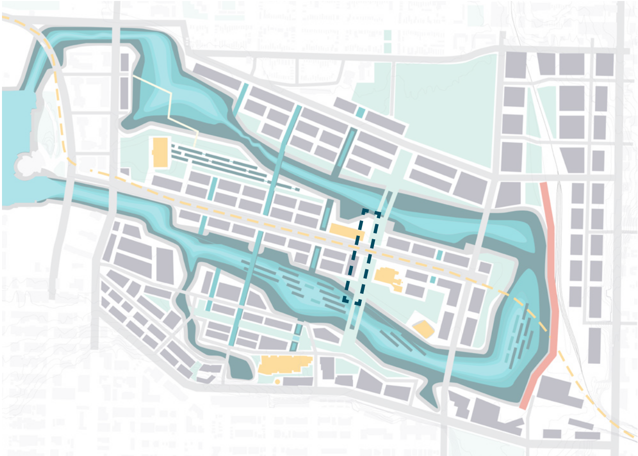
Terminal Avenue and Vancouver Flea Market - Plan View
Scale: 1:1000 (Figure 4.4-1)

Design Intent

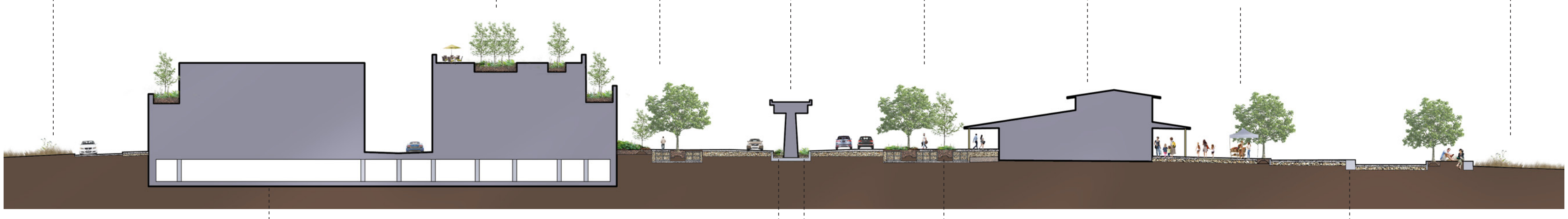
The Vancouver Flea Market is a popular venue in the False Creek Flats. As the area redevelops, this site should be retained as a public market, which could help contribute to the vibrancy of the area. The proposed design considers enhancing this space by including room for an outdoor market that could also provide opportunities for pop-up events. The design proposes to incorporate crush gravel in this area to increase the permeability of the site.

The design also proposed to convert the area beneath the Expo Line into an infiltration swale, to help capture stormwater runoff from Terminal Avenue. To make stormwater management more visual in the landscape, the proposed design incorporates a pattern of runnels on Terminal Avenue, which can also help reduce the speed of traffic by acting as rumble strips.

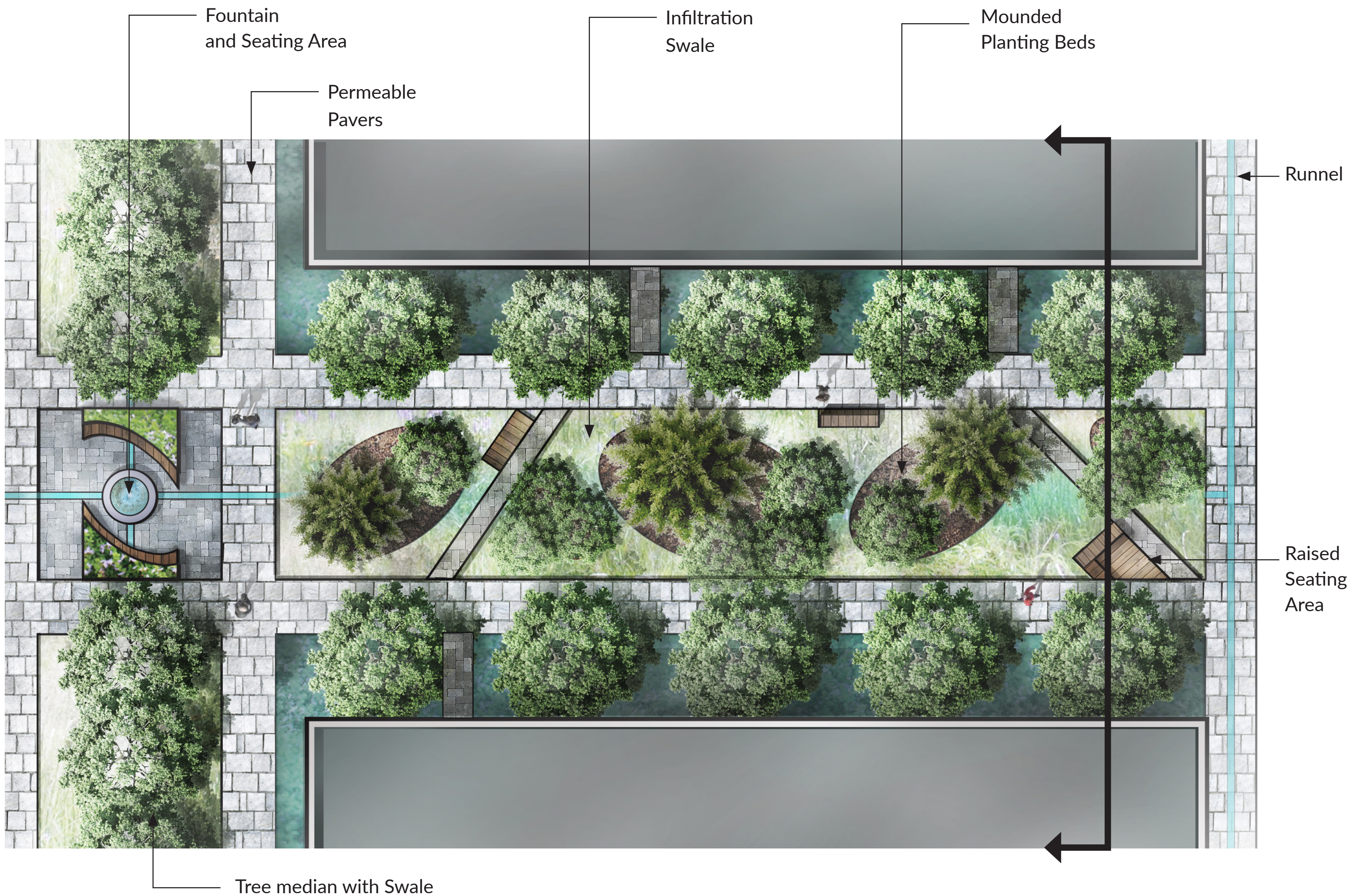
The proposed design looks to apply a variety of low impact development features, including green roofs, permeable pavers, rain gardens, and absorbent landscapes that transition into the constructed wetland.



Context Map - Terminal Avenue and Flea Market
(Figure 4.4-3)



Terminal Avenue and Vancouver Flea Market - Cross Section
Scale: 1:1000 (Figure 4.4-2)



Low Impact Development Campus Outdoor Mall - Plan View

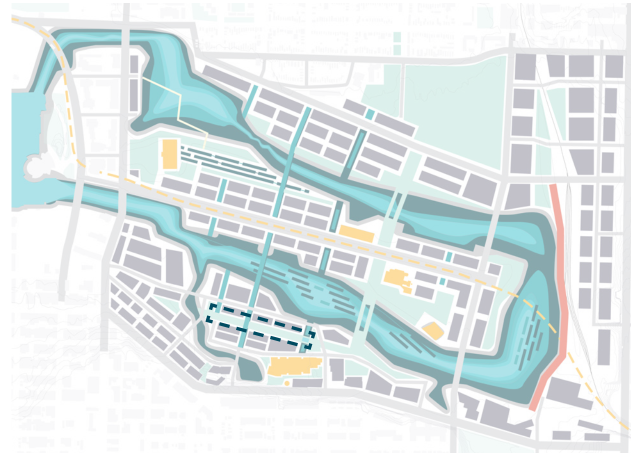
Scale: 1:500 (Figure 4.4-4)

Design Intent

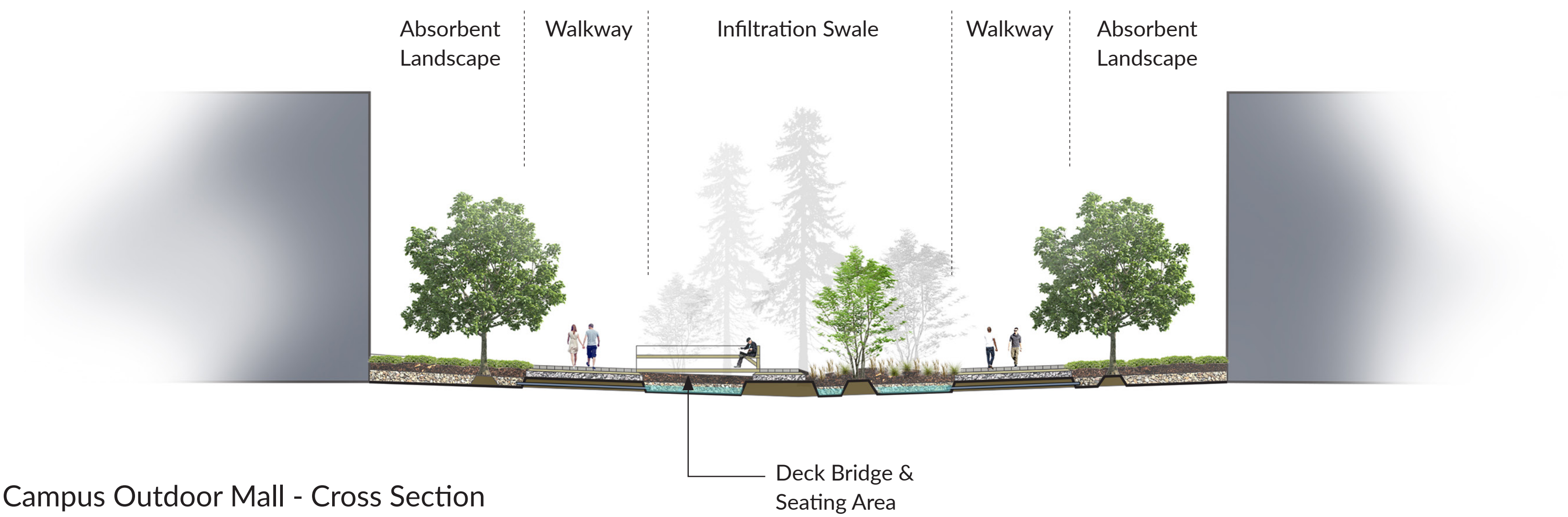
It is expected that the campus that surrounds Emily Carr University and BCIT will continue to expand. As the campus grows it will be important to integrate additional public space for students and faculty. The proposed Campus Outdoor Mall takes inspiration from the landscape mall at the University of British Columbia, which provides a pedestrian focused armature for the campus.

The proposed design includes a large infiltration swale landscape with raised planting mounds, which could incorporate trees and shrubs that may have surrounded the False Creek Flats prior to the land clearing during the early industrial development of the area, creating a landscape for people to learn about the history of the area. The design also incorporates sitting areas an pathways through the landscape to enhance the pedestrian experience and circulation. Landscaped beds adjacent to the buildings also help to absorb stormwater runoff and direct drainage towards the infiltration swale.

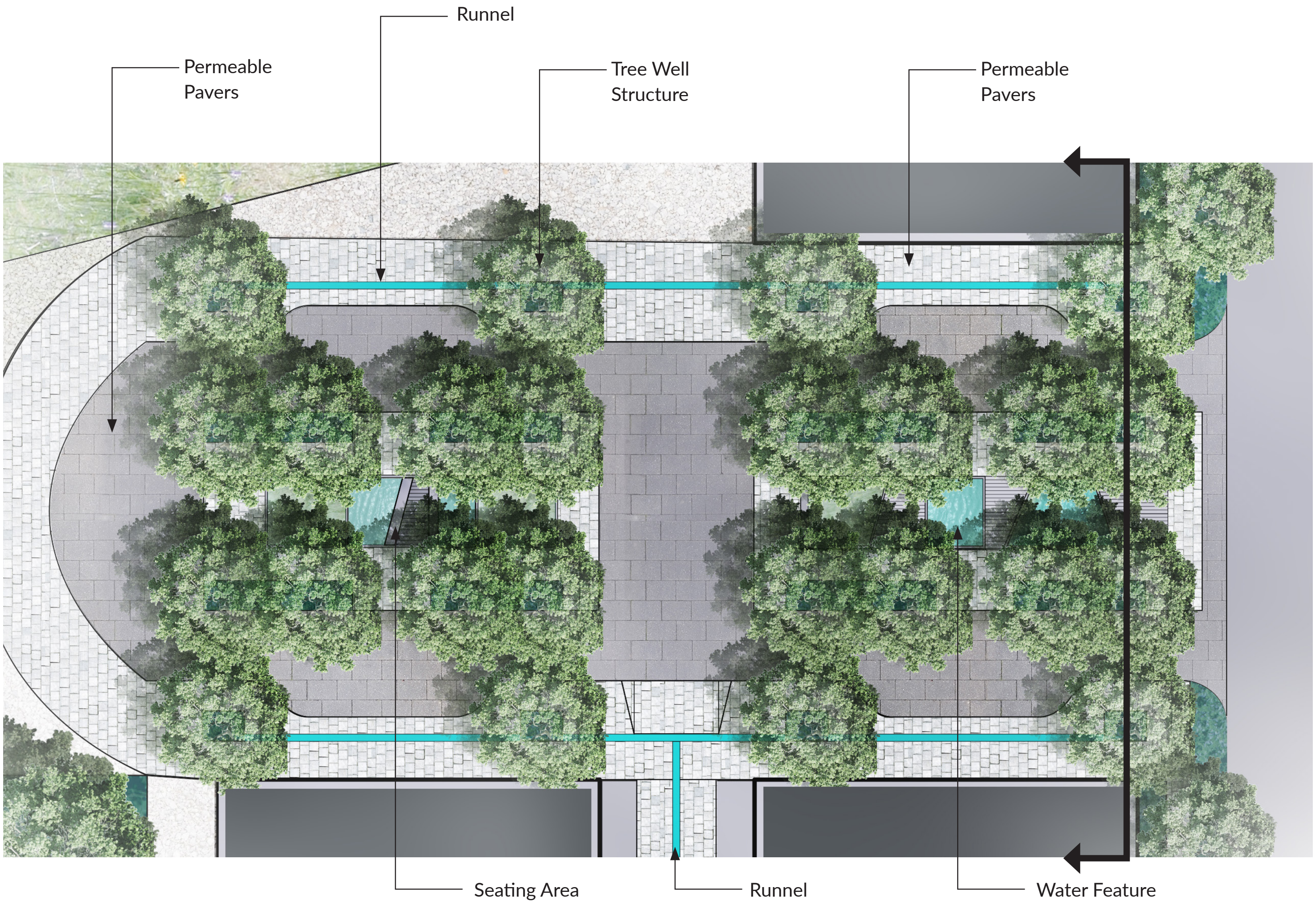
The design also proposes gathering areas at the intersections of roads and paths. These can be focal points and runnels that lead to the swale helps encourage an awareness and connection to water on the site.



Context Map - Campus Outdoor Mall
(Figure 4.4-6)



Campus Outdoor Mall - Cross Section
Scale: 1:300 (Figure 4.4-5)



Low Impact Development Destination Street - Plan View

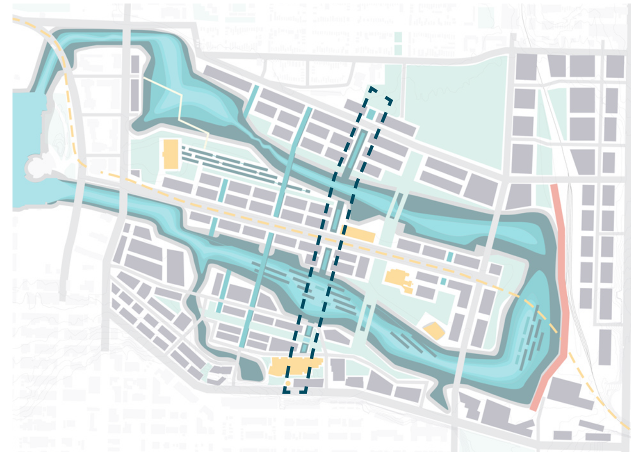
Scale: 1:500 (Figure 4.4-7)

Design Intent

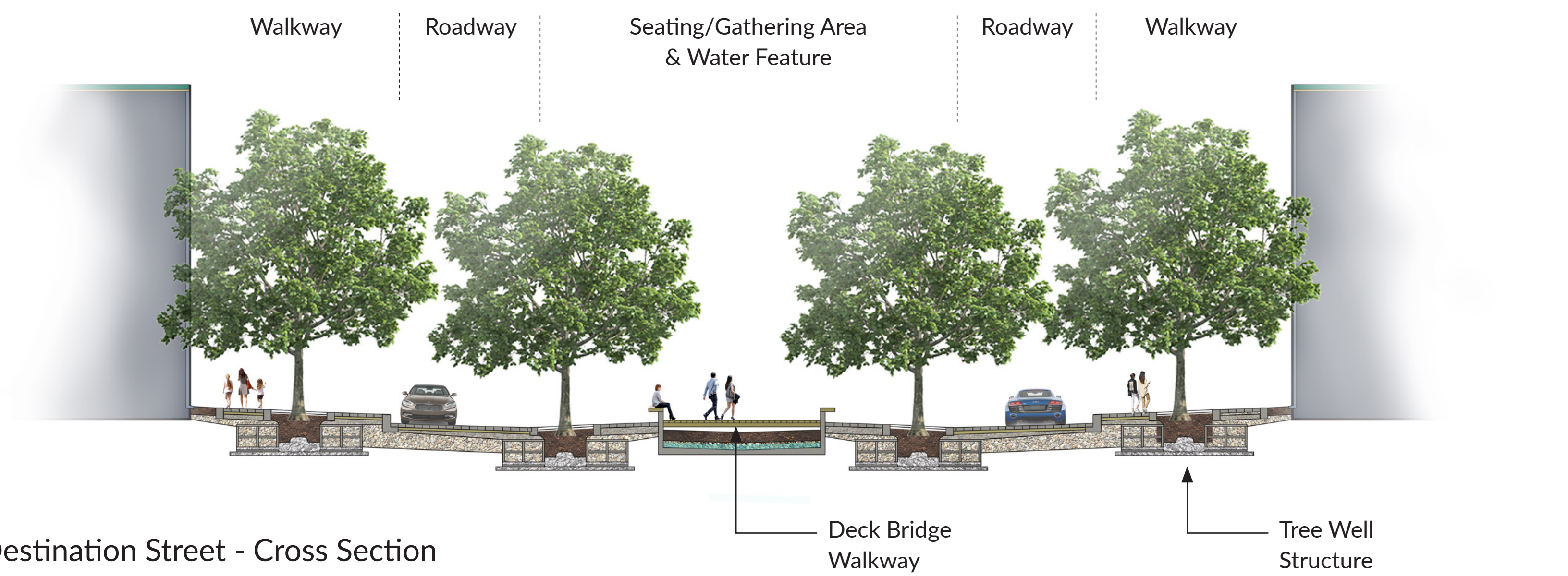
To enhance the image and structure of the False Creek Flats to provide legibility, street types can be incorporated providing a sense of hierarchy and direction within the site. The 'Destination Street' can act as a node within the False Creek Flats, through the incorporation of the seating area and water feature in the centre of the street.

To help ensure the success of the street trees in this area, the design proposes the use of tree well structures to provide support underneath the walkway and roadways. Permeable pavers are also proposed to help allow for the infiltration of stormwater, and runnels help direct water towards the tree well structures.

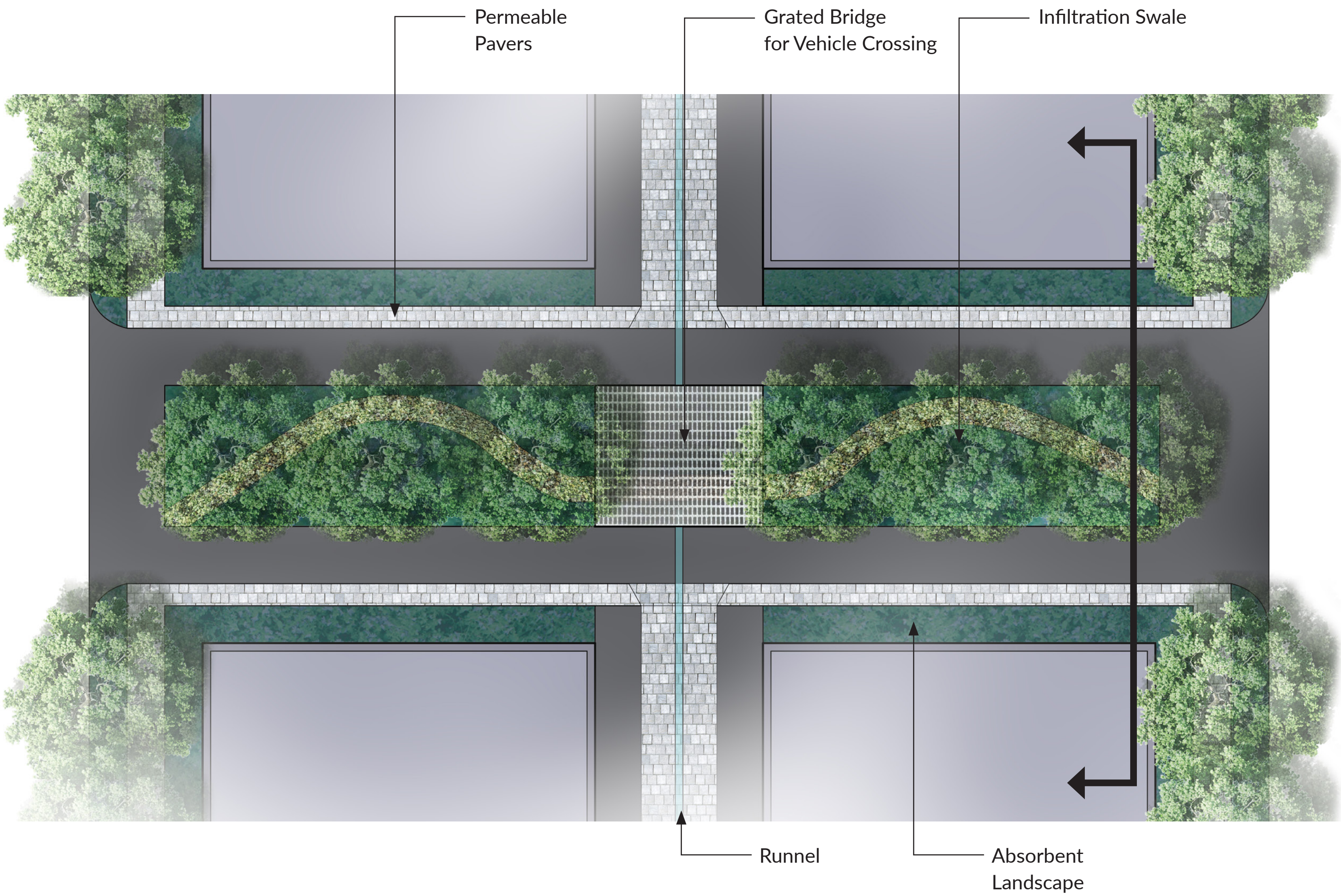
Curb bump-outs also help make the area more walkable for pedestrians by reducing travel distances over roadways and provide limited room for street parking. The texture of paving stones used for roadways can also help signal to drivers to reduce their speed for pedestrians.



Context Map - Destination Street
(Figure 4.4-9)



LID Destination Street - Cross Section
Scale: 1:300 (Figure 4.4-8)



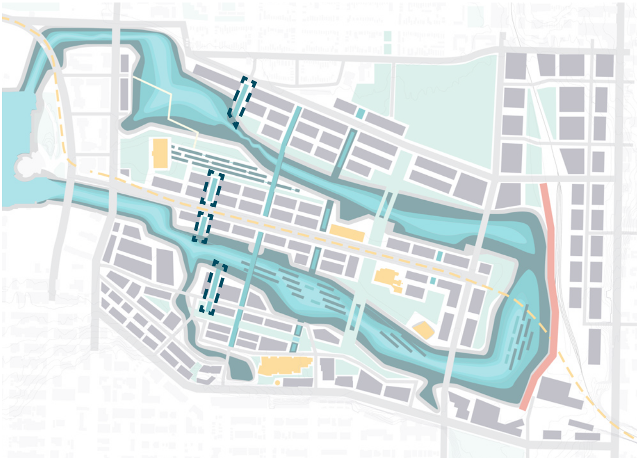
Low Impact Development Small Street - Plan View

Scale: 1:500 (Figure 4.4-10)

Design Intent

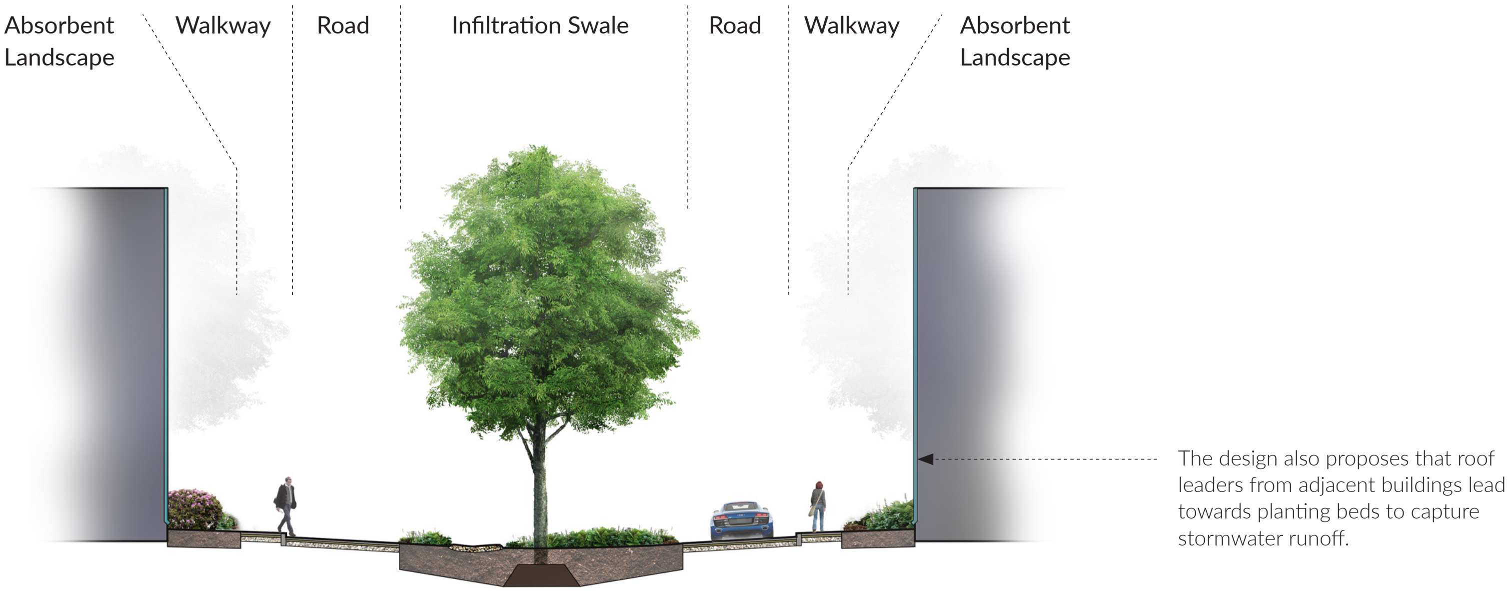
Similar to the Destination Street, the Small Street can contribute to providing a sense of hierarchy within False Creek Flats, while also incorporating low impact development features. This design proposed a curbless centre median that collects water into a infiltration swale that directs water towards the constructed wetland area.

The design also proposed a runnel to collect water in the alleyways and a metal grated bridge allows vehicles to cross the swale. Permeable pavers are proposed for the walkways to help the infiltration of stormwater.



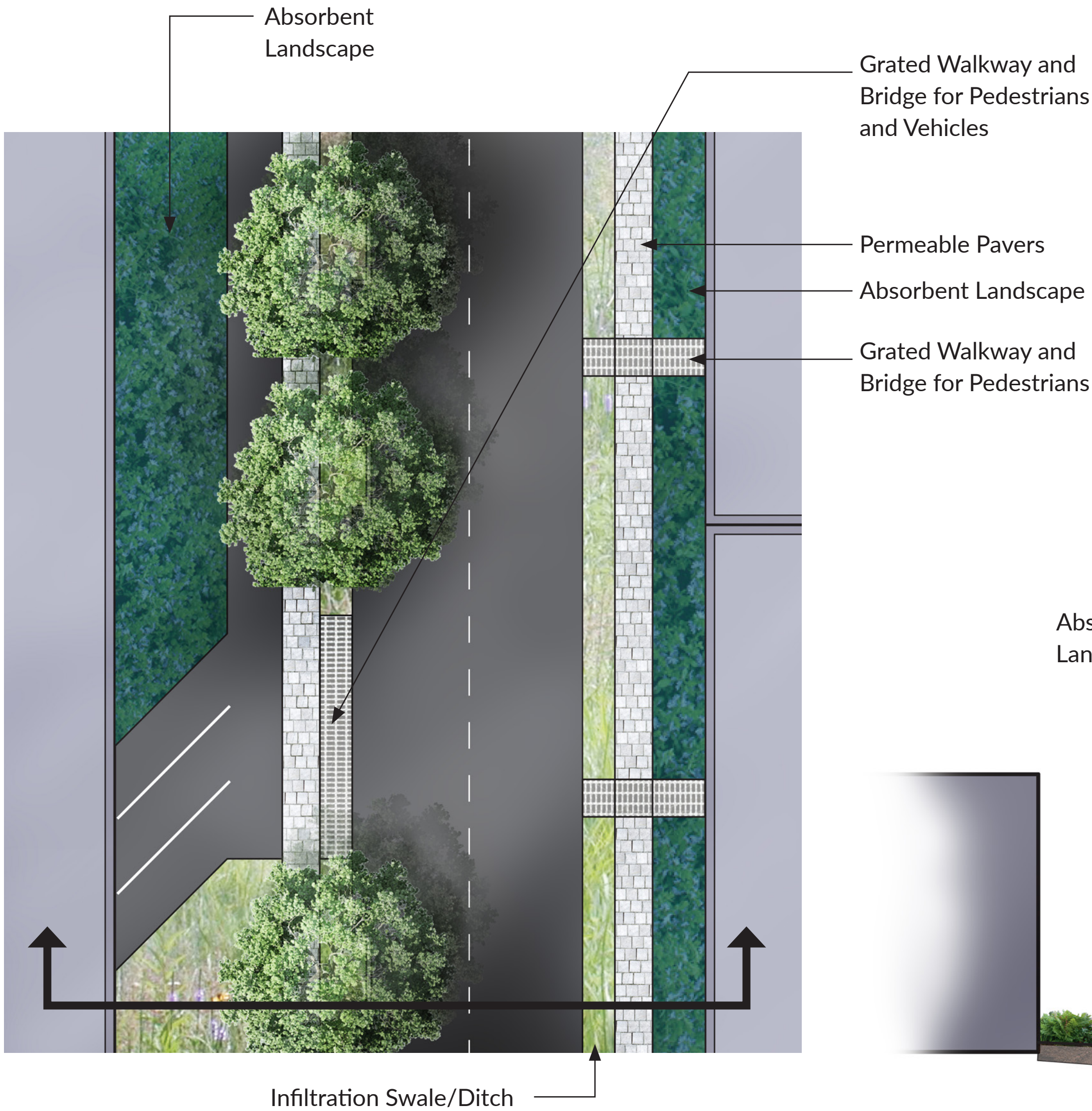
Context Map - Small Streets

(Figure 4.4-12)

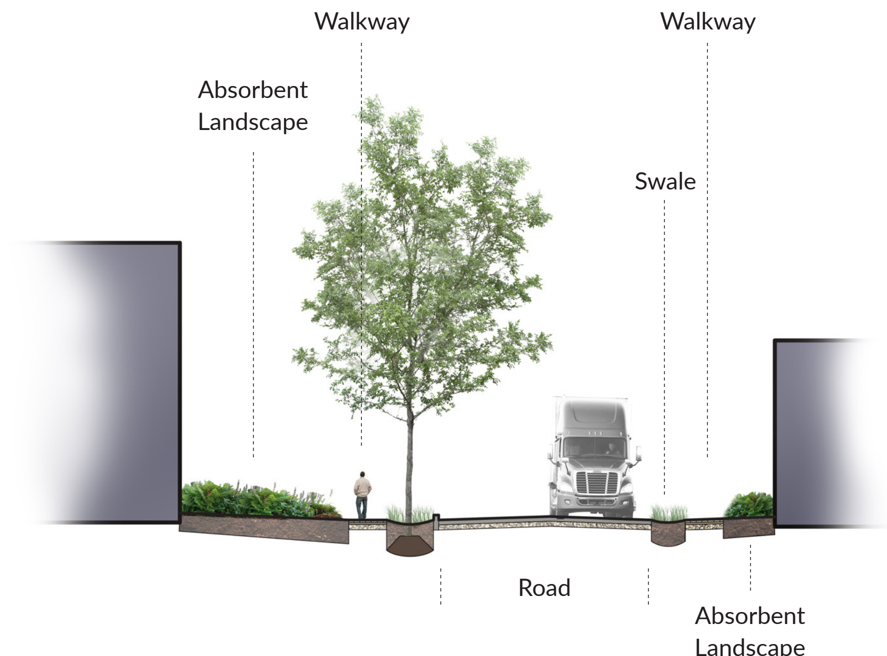


Low Impact Development Small Street - Cross Section

Scale: 1:300 (Figure 4.4-11)



Low Impact Development Industrial Street - Plan View
Scale: 1:300 (Figure 4.4-13)

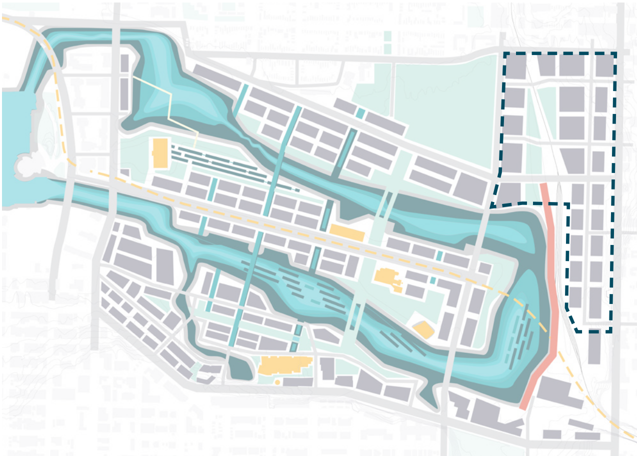


Industrial Street - Cross Section
Scale: 1:300 (Figure 4.4-14)

Design Intent

As it is anticipated that the False Creek Flats will continue to support industrial activities, the design proposes a ditch/swale to collect stormwater. This low impact development feature will not only collect water, it also provides a buffer for pedestrian walkways to enhance the pedestrian experience.

The inclusion of trees also helps provide vegetation to encourage evapotranspiration, which can reduce temperatures during summer months, while also providing shade to this highly impermeable environment.



Context Map - Industrial Area
(Figure 4.4-17)

Existing Industrial Street
(Figure 4.4-15)

Proposed Industrial Street
(Figure 4.4-16)

4.5 Emergence of a Coastal Wetland

Shifting Shorelines in False Creek

As sea levels continue to rise, the extent of the high and low water levels will correspondingly increase.

The following diagrams show the current average high and low water levels, and speculate the high water levels taking into account a 1 m rise in sea level by the year 2100. Figure 4.5-2 shows the extent of the high water levels during a 1:500 event in the year 2100.

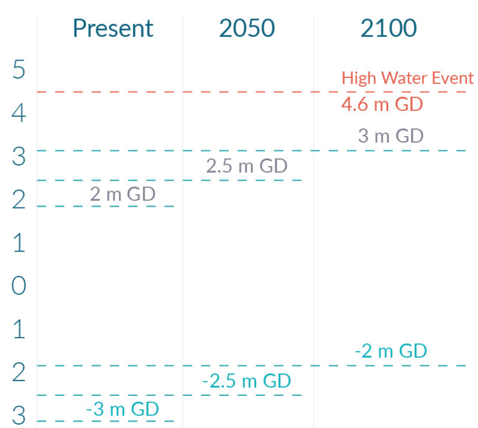
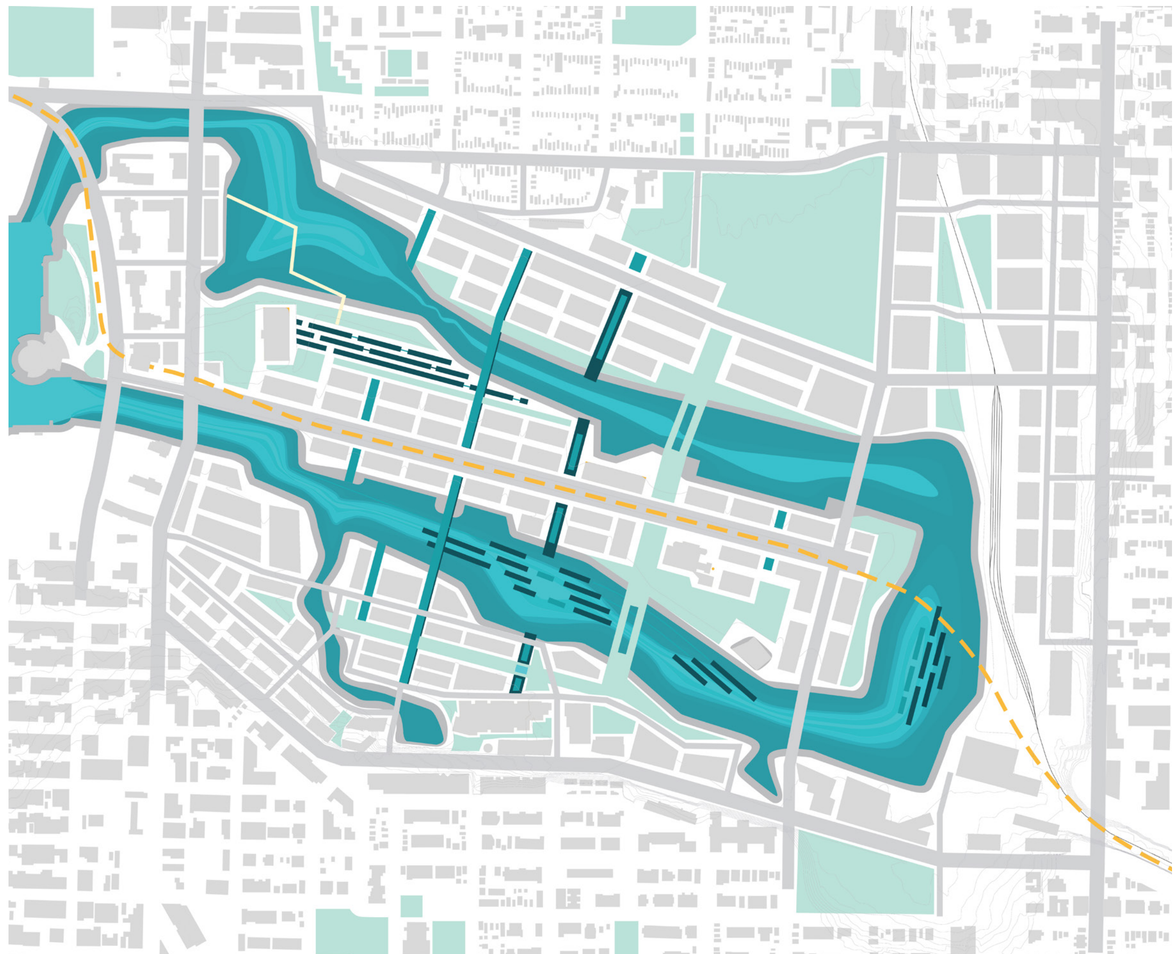


Figure 4.5-1
Shifting Water Levels

These water levels represent the one meter rise in sea levels as projected by the province of B.C.



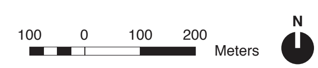


Figure 4.5-2
High water event (500 return period) with 1 m of sea level rise in the year 2100, reaching approximately 4.6 m GD (based on current Flood Construction Level for False Creek Flats).

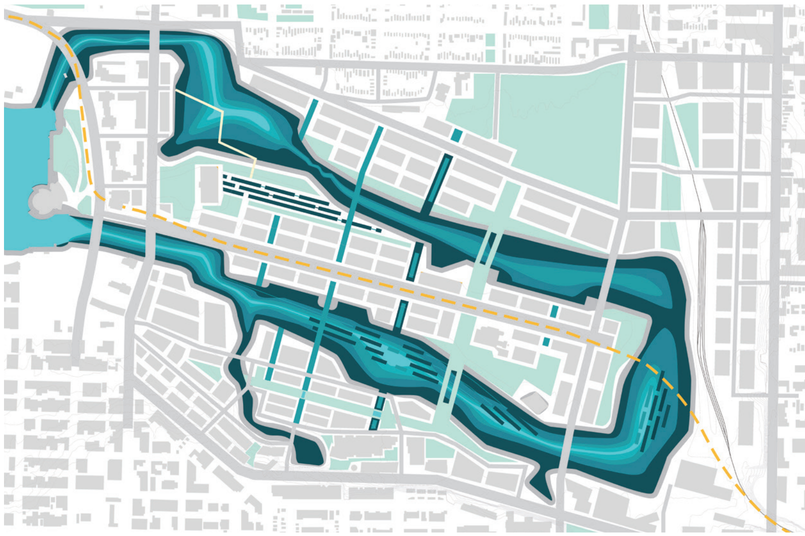


Figure 4.5-3
Current average low water level, approximately -3 m GD.

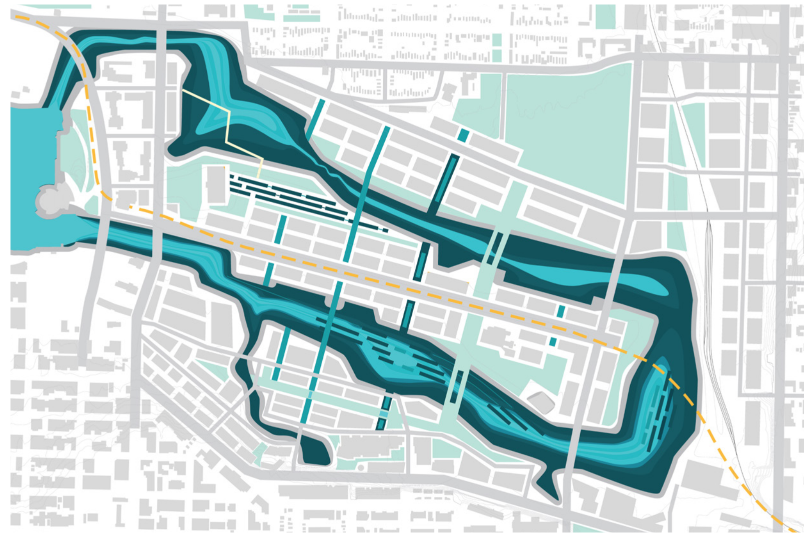


Figure 4.5-4
Current average high water level, approximately 2 m GD.

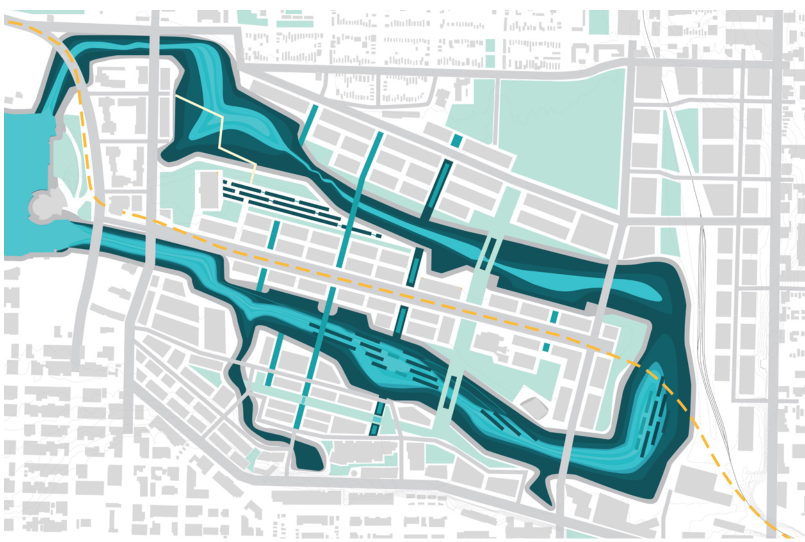


Figure 4.5-5
Approximate average high tide by 2050, with 0.5 m rise in sea level reaching approximately 2.5 m GD.

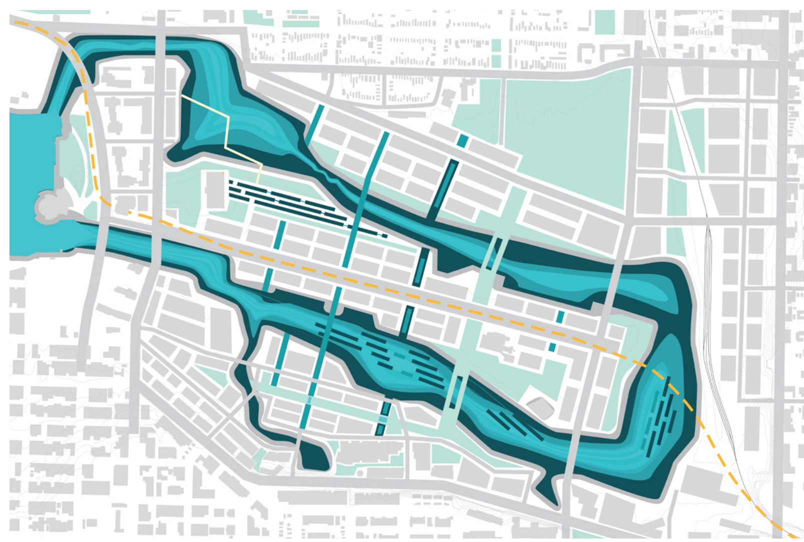


Figure 4.5-6
Approximate average high tide by 2100, with 1.0 m rise in sea level reaching approximately 3 m GD.

Plant Zones and Water Levels

Plants along the coast are distributed in relation to sea levels. On the next page is a cross section of plant zones in relation to current water levels. However, as the tidal extent raises with sea level rise, the location of plant zones will shift upland.

This will be an integral aspect of the design to allow people to experience the changing landscape, one that dynamically responds to coastal processes and indeterminate change. The shifting landscape will also allow for new opportunities to emerge and new experiences. As the plant zones shift, so will aquatic and terrestrial habitats creating a diverse and rich urban ecology.

A consequence of this shift and urban development is that the process of ‘coastal squeeze’ will continue to occur as sea levels continue to rise. This design, however, will help provide refuge to coastal wildlife and aquatic species as other coastal edges in the city become inundated with sea level rise.

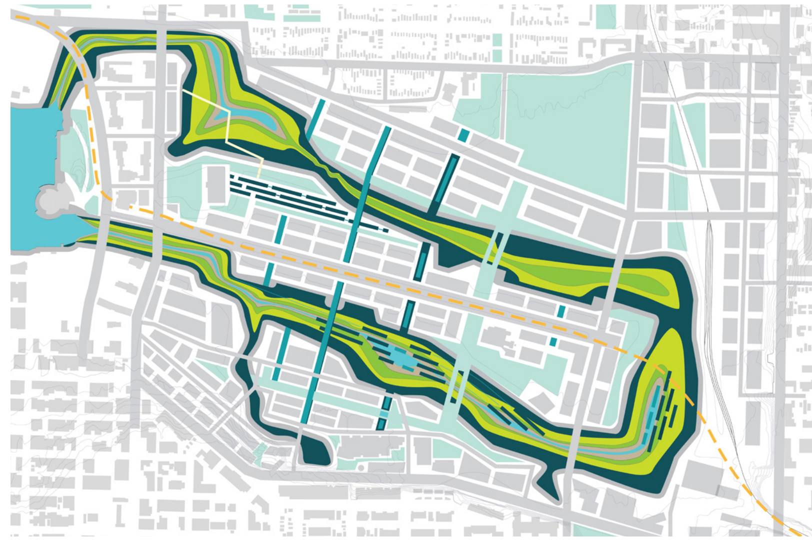


Figure 4.5-7
Plant zone distribution under current water level conditions.

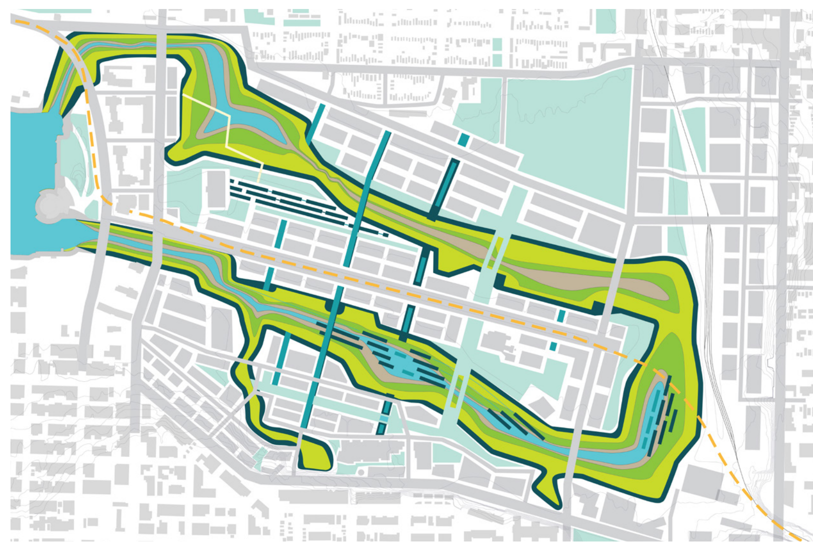


Figure 4.5-8
Plant zone distribution for the year 2100.

Legend

- Riparian
- Dunegrass
- Salt Marsh
- Mudflat
- Water

Figure 4.5-9
Cross Section of coastal plant zones in relation to current water levels.

As sea level rises, plant zones will shift upland. To gain a better understanding of local wetlands, preliminary drawings for the restored wetland at New Brighton Park (Moffat & Nichol, 2016, p. 7), and the restored shoreline in Delta for the East Causeway Habitat Compensation Project (G.L. Williams & Associates Ltd. and Coast River Environmental Services Ltd., 2006, p. 10), were reviewed for plant zone distribution in relation to water levels.

Salt Marsh

seacoast bulrush
saltgrass
gumweed
seacoast plantain
pickleweed
tree-square bulrush
seacoast arrowgrass

Herbs

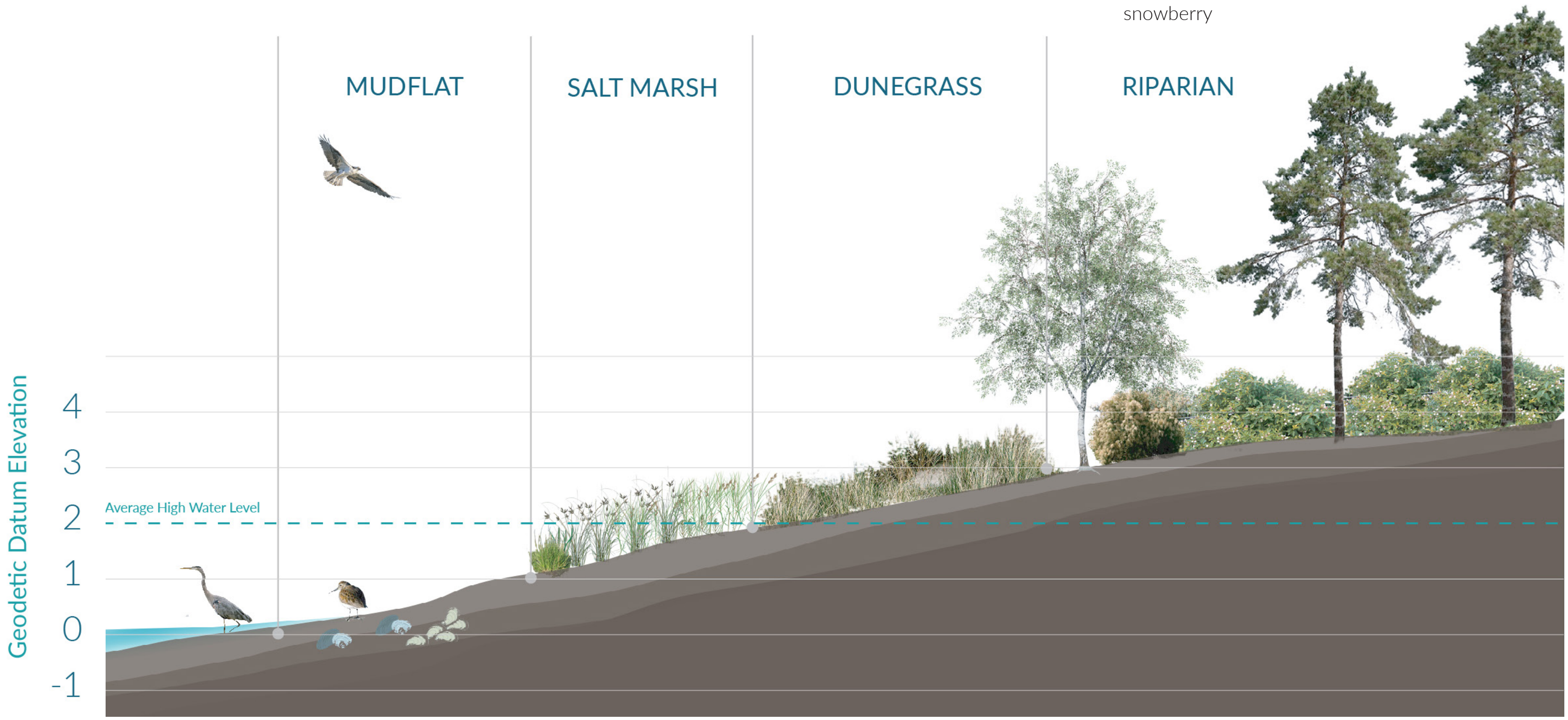
silver burweed
large-headed sedge
purple peavine
dunegrass
Pacific sanicle

Shrubs

salal
ocean spray
trumpet honeysuckle
black twinberry
dull oregon-grape
false azalea
sweet gale
baldhip rose
salmonberry
Hooker's willow
red elderberry
hardhack
snowberry

Trees

bigleaf maple
red alder
arbutus
paper birch
flowering dogwood
black hawthorn
Pacific crabapple
shore pine
Sitka spruce



4.6 Cultivating Opportunities to Connect with the Landscape

The following design interventions suggest opportunities that could allow people to engage with the constructed wetland as well as public space to support and contribute to the livability and vibrancy of the False Creek Flats. These areas include the:

- Tidal Flat Park
- Pacific Central Station Park
- Mountaineer Station Park and Plaza, and
- Boxcar Habitat Island

The context diagram on the right shows the location of each area explored.

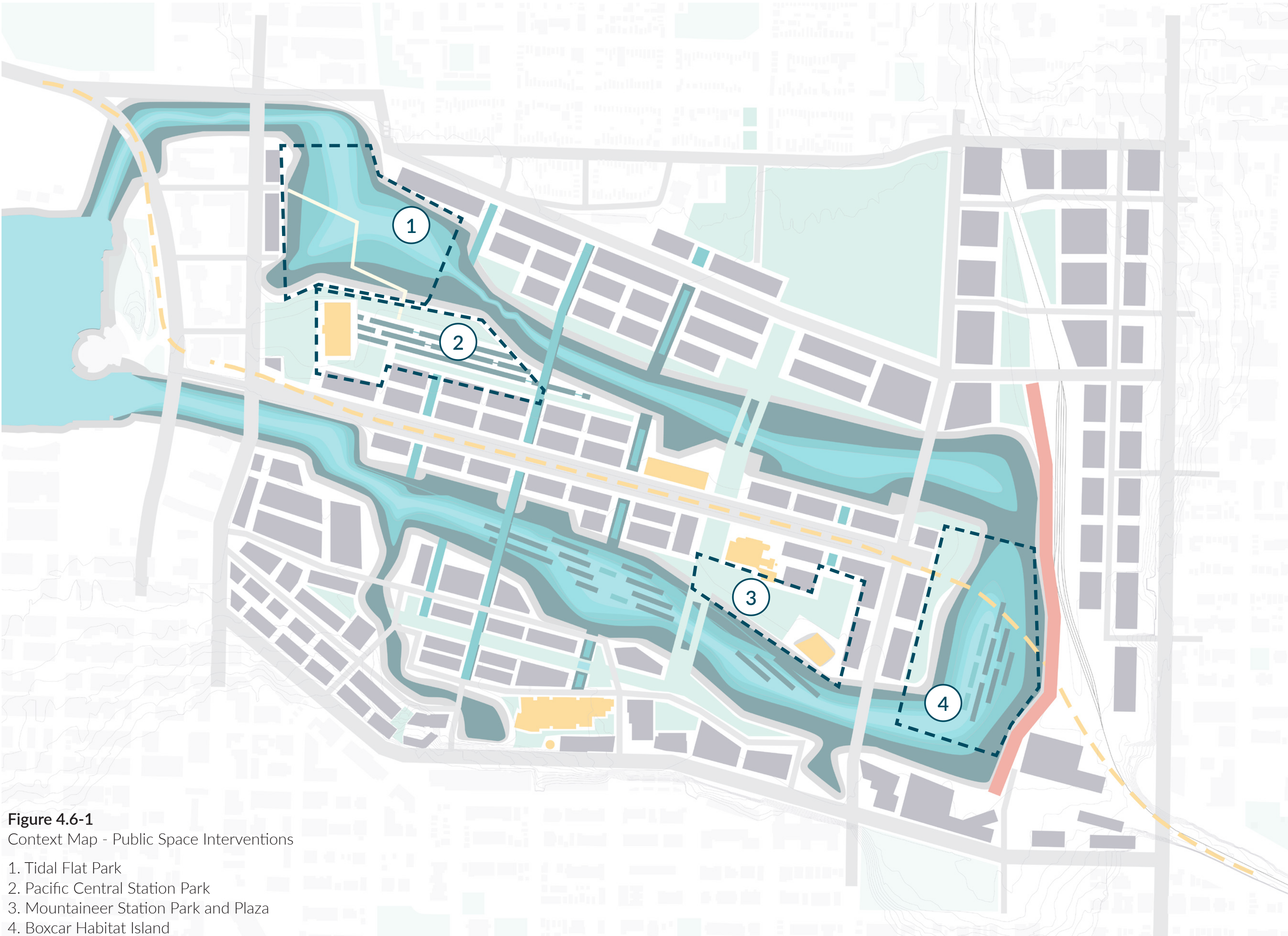
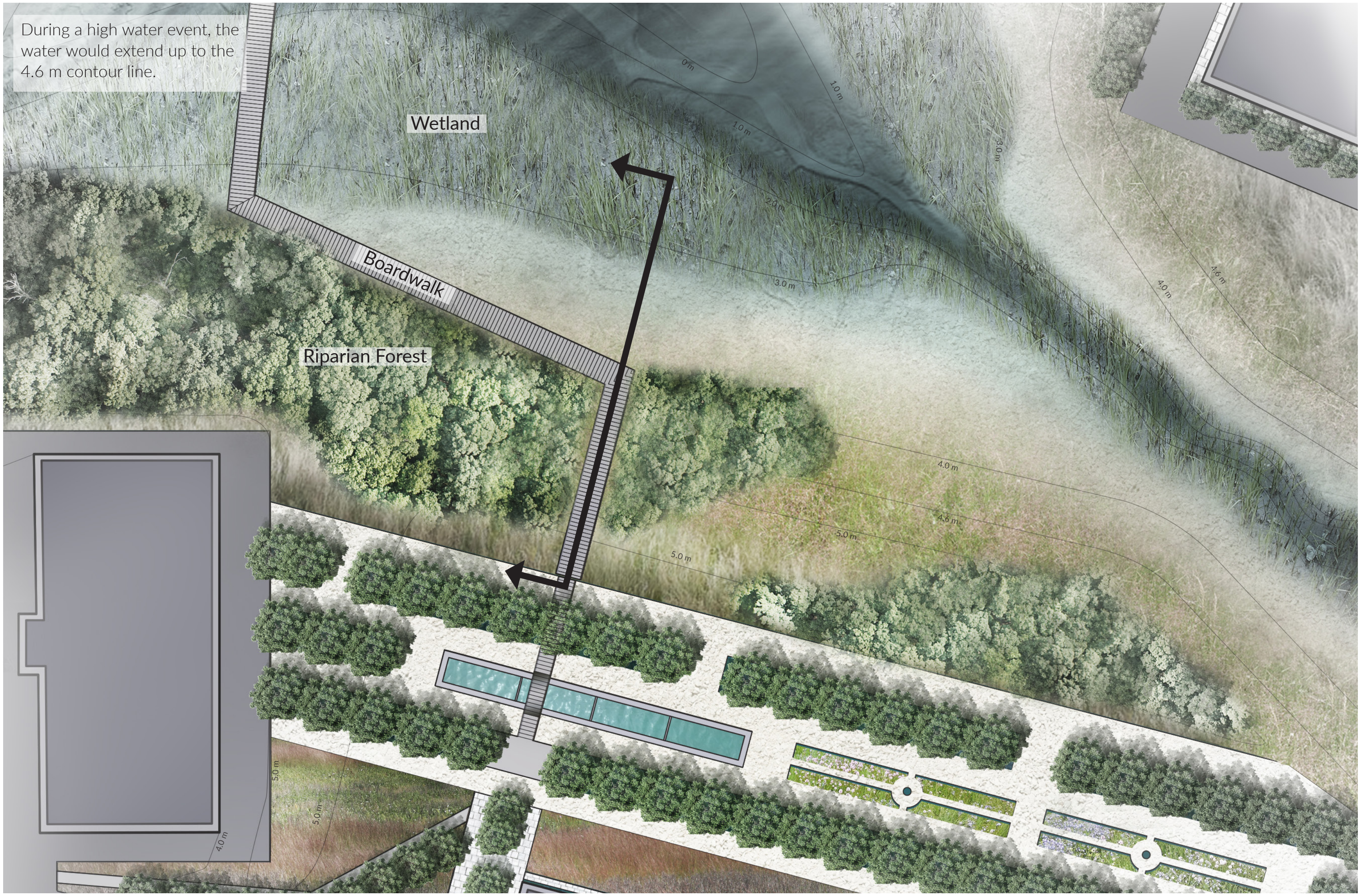


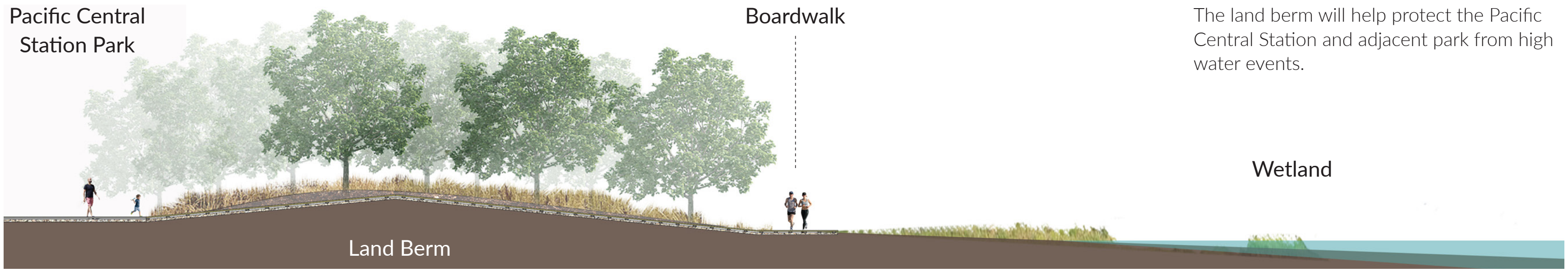
Figure 4.6-1
Context Map - Public Space Interventions

1. Tidal Flat Park
2. Pacific Central Station Park
3. Mountaineer Station Park and Plaza
4. Boxcar Habitat Island



Tidal Flat Park - Plan View

Scale: 1:1750 (Figure 4.6-2)

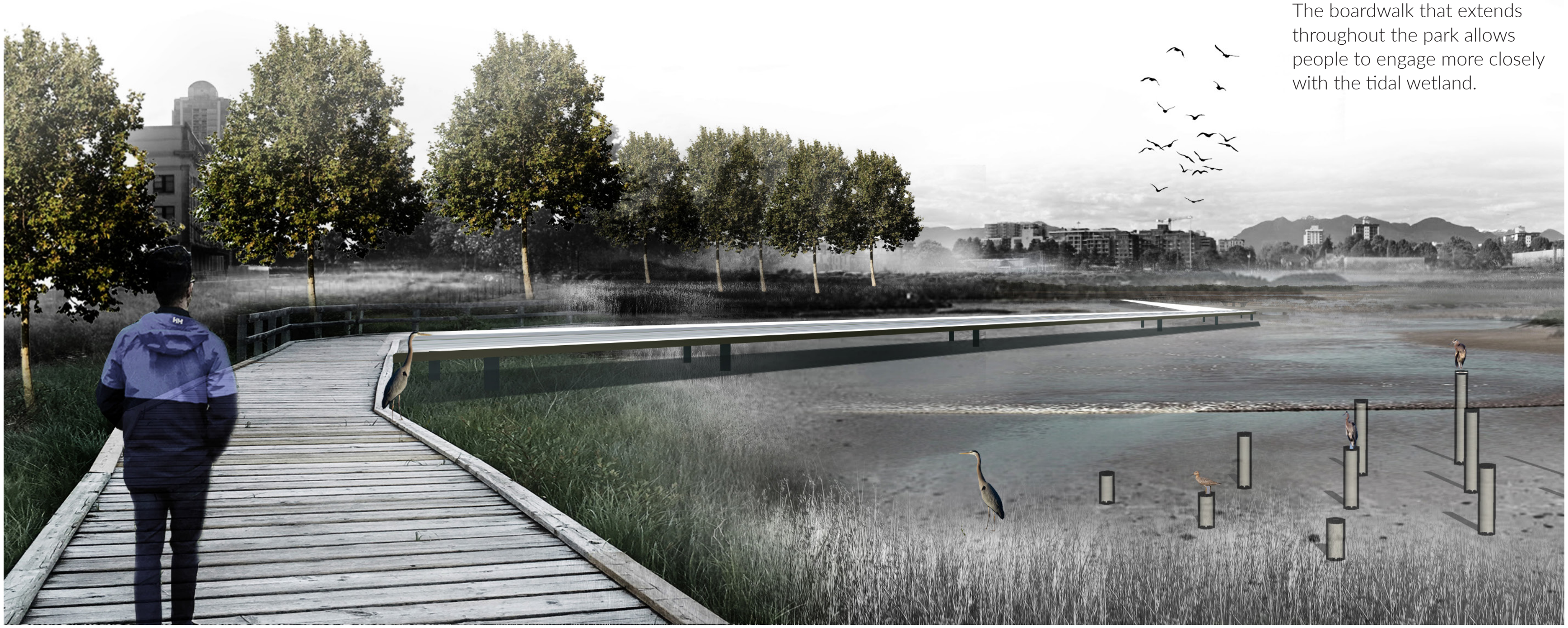


The land berm will help protect the Pacific Central Station and adjacent park from high water events.

Tidal Flat Park - Cross Section

Scale 1:500 (Figure 4.6-3)

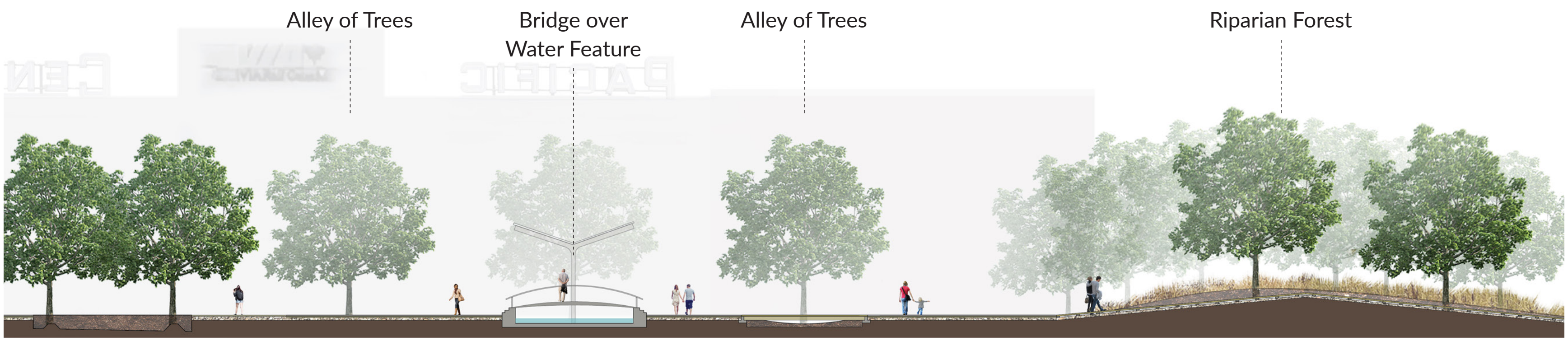
The boardwalk that extends throughout the park allows people to engage more closely with the tidal wetland.



Tidal Flat Park Looking West - Perspective

Not to Scale (Figure 4.6-4)

Pacific Station Park - Plan View
Scale: 1:1750 (Figure 4.6-5)



Pacific Station Park Cross Section

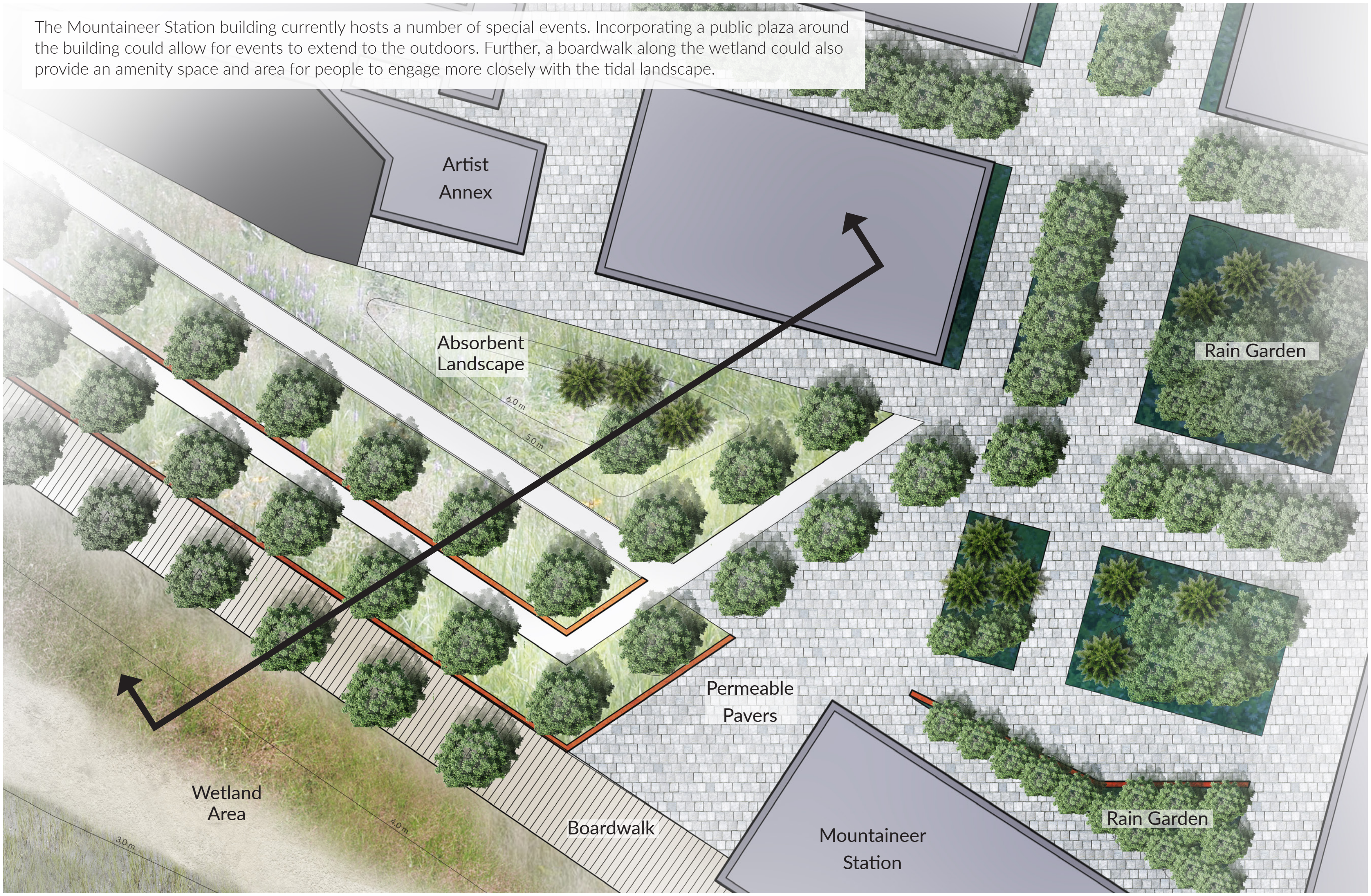
Scale 1:500 (Figure 4.6-6)

Pacific Station Park Looking West - Perspective

Not to Scale (Figure 4.6-7)

The design proposes to incoroporate features from the Pacific Central Station, such as the seating shelters that are currently used at the train station.

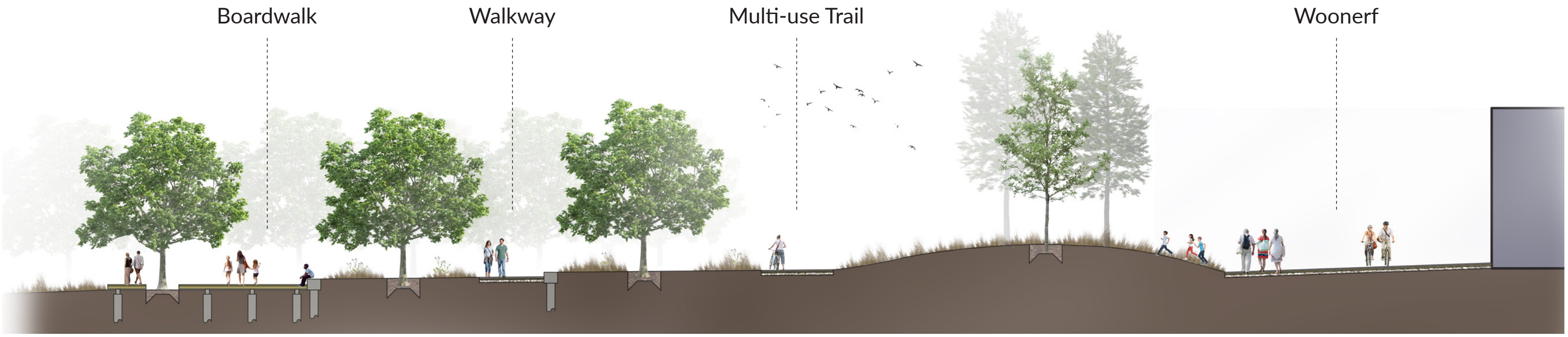
The Mountaineer Station building currently hosts a number of special events. Incorporating a public plaza around the building could allow for events to extend to the outdoors. Further, a boardwalk along the wetland could also provide an amenity space and area for people to engage more closely with the tidal landscape.



Mountaineer Station Park and Plaza - Plan View

Scale: 1:1500 (Figure 4.6-8)

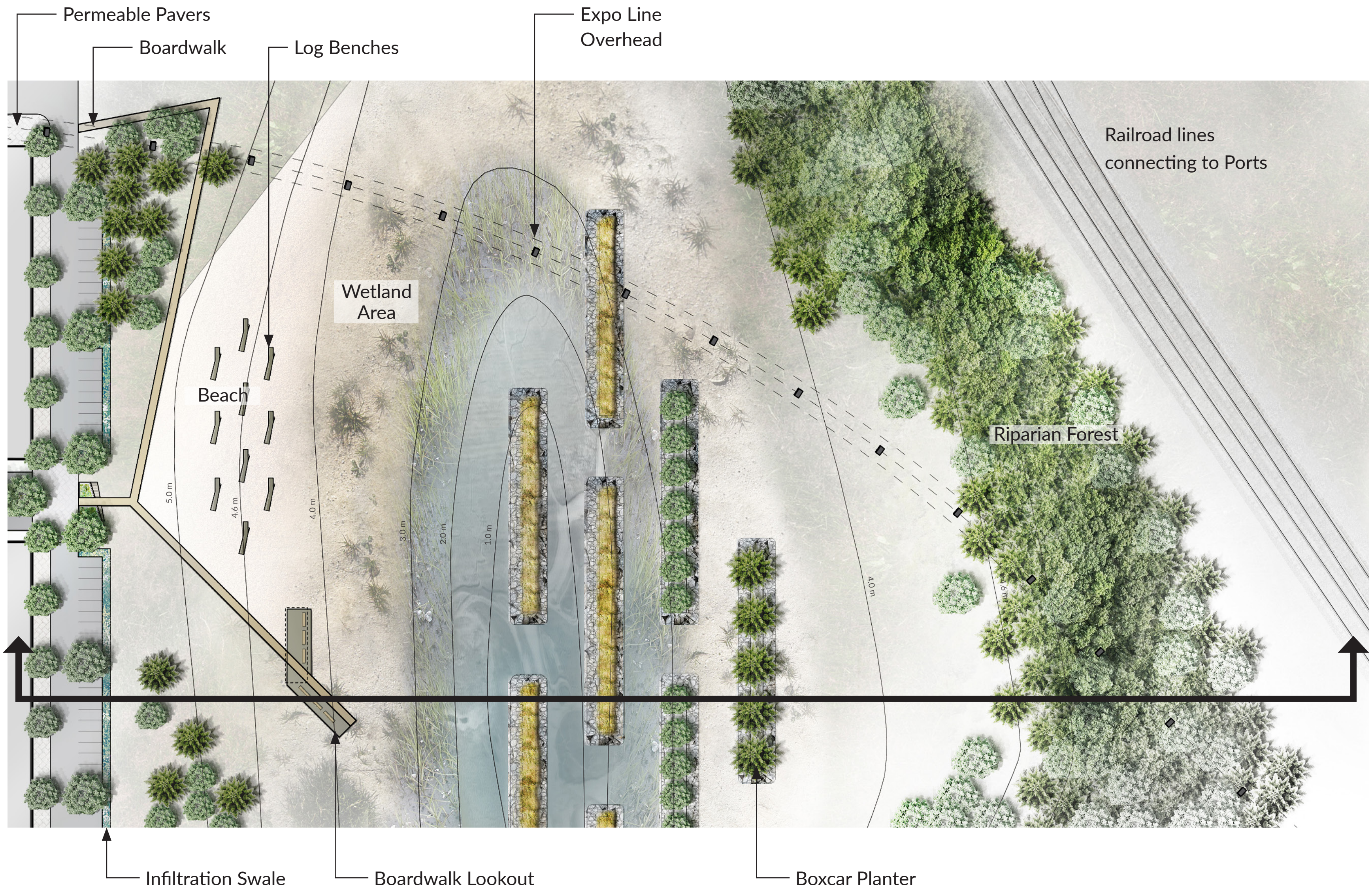
The terraced walls that transition towards the wetland offer areas to hint at the history of the site, such as imprints of salmon that previously traveled through the historic tidal flat to nearby streams.



Mountaineer Station Park - Cross Section
Scale 1:500 (Figure 4.6-9)

Mountaineer Station Park Trail - Perspective
(Figure 4.6-10)

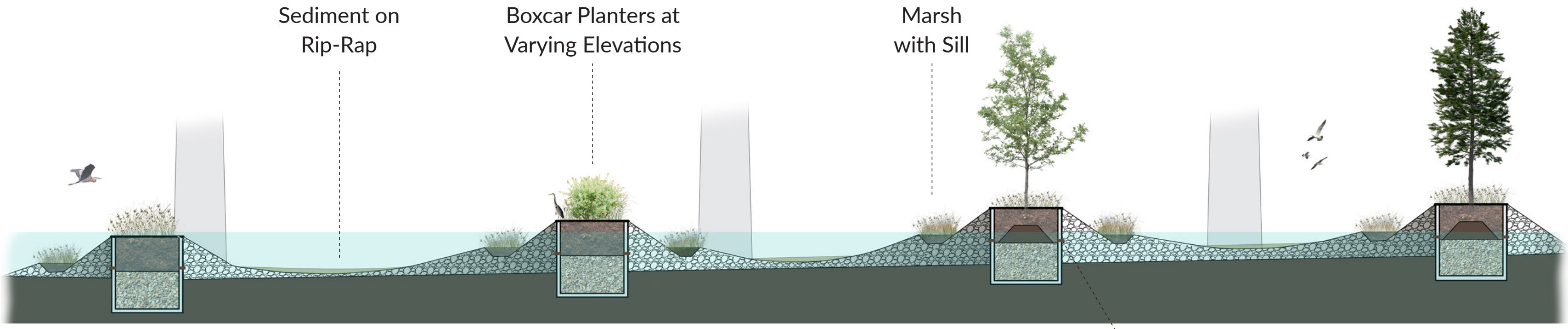
Mountaineer Station Park Boardwalk - Perspective
(Figure 4.6-11)



Boxcar Habitat Island - Plan View

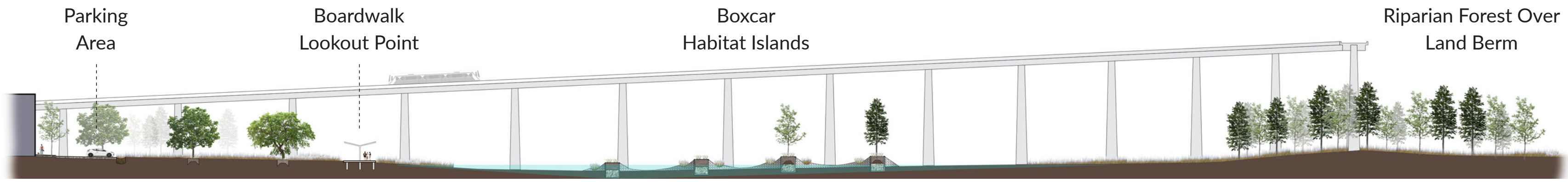
Scale: 1:1500 (Figure 4.6.12)

The Boxcar Planters are a play on the history of the site and the dominance of rail infrastructure. The design proposes to convert the boxcars to planters at varying heights to support different types of plants in relation to different water levels.



Boxcar Habitat Island - Cross Section Enlargement

Scale: 1:300 (Figure 4.6.13)

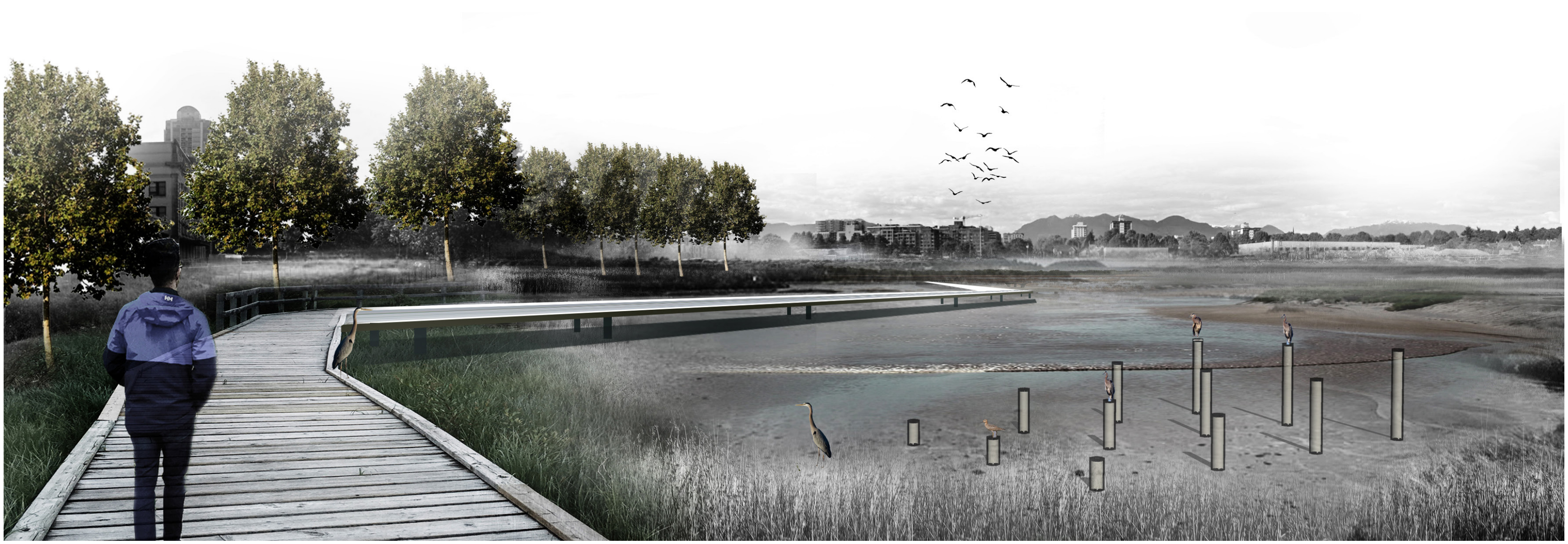


Boxcar Habitat Island - Cross Section

Scale: 1:1500 (Figure 4.6.14)

Boxcar Habitat Island - Perspective

Not to Scale (Figure 4.6.15)



Conclusion

As identified by the IPCC (2018), it is expected that even with the changes society is making to reduce our carbon footprint and our impact on the environment, temperatures and sea levels will continue to rise. Coastal landscapes are inherently resilient to changing conditions, being able to respond to disturbances whether it be tidal waters influenced by the weather or changing sea levels. These disturbances generate and support rich ecosystems supporting a diversity of plants, birds, aquatic species and other wildlife. Coastal landscapes are also desirable to people, and over time, have been, and continue to be, developed by filling in or reclaiming the land to make room for growing cities. However, this is often at the cost of severing the connection the land has to coastal waters and the natural systems that support them, which was also the case for the False Creek Flats.

Historically, the False Creek Flats was a tidal flat that hosted a rich ecology of plants and wildlife; however, its ecological value diminished once Europeans settled in Vancouver and the tidal flat was filled in to accommodate rail and industrial development. Today, the importance of rail as an economic driver for the city has lessened, although its physical presence still dominates the character of False Creek Flats. With the City of Vancouver anticipating that the False Creek Flats will emerge as one of Vancouver's employment hubs, they have developed a redevelopment plan to guide future growth and development within the area. Also acknowledging that Vancouver will be impacted by sea level rise and climate change, the City of Vancouver commissioned two reports to assess the coastal flood risks Vancouver will face and high-level approaches to managing the impacts. These assessments also proposed solutions for False Creek and the False Creek Flats, as both areas will be prone to flooding. Unfortunately, adaptive solutions were not explored in great detail to identify how the False Creek Flats could be developed to make room for sea level rise. Also missing from the coastal flood risk discussion is a meaningful way to address stormwater which will compound the flood risk issues in the False Creek Flats, as it is projected that the Vancouver region will receive more precipitation over the next century with more intense and frequent storms.

Figure C.0 - 1
Tidal Flat Park Perspective

To find a more resilient approach to redevelop False Creek Flats, this practicum explored a variety of strategies to manage sea level rise and stormwater through three lenses: robustness, to ensure people are safe; adaptive, to make room for the water to reduce flood damage; and a transformative approach, to shift perspectives on how we live and build with water.

Through the robust approach, it is clear that there will be tough decisions to be made as to how flood-prone areas will be dealt with as sea level continues to rise. Some areas, such as those in the Woodbridge Township, need to retreat from unsafe areas in order to make room for flood storage, while also to protect the health and safety of people. However, the Woodbridge Township case study demonstrated that areas retreated from not only provide the benefit of making room for flood waters, the newly created open space also became a public amenity, providing opportunities to engage with the environment, while also providing habitat areas for wildlife. This approach is similar to Corktown Common, where the landform berm protects the West Don Lands from flood waters from the Don River, while also providing a public park that includes a constructed marsh that supports migratory birds and local wildlife, as well as manages stormwater for water efficiency. The HafenCity case study illustrated an adaptive approach to sea level rise by reconstructing a historic port into a development that intentionally makes room for flood waters and incorporates flood infrastructure to ensure the safety of lower levels of development.

Other adaptive strategies reviewed identified best practices for low impact development to use landscape infrastructure to manage stormwater while also creating other benefits, such as micro-habitats for urban wildlife and reducing temperatures through evapotranspiration. Adaptive strategies for coastal landscapes include living shorelines and coastal wetlands where landscape-based strategies minimize the impact of sea level rise, providing greater stability to shorelines while also providing ecological benefits for wildlife. Finally, the concept of aesthetic performance suggests a transformative approach to coastal resilience by providing people opportunities to engage with the landscape and using design to raise awareness on the impact climate change will have on our environment. The aesthetic performance of landscapes can also passively educate people on the interconnected natural systems to help shift perceptions of how cities should be built to respond and work with natural processes. Collectively, these strategies have informed a design strategy for False Creek Flats to make room for both sea level rise and stormwater. The strategy also visualizes opportunities for people to engage with the landscape, to appreciate the beauty of False Creek Flats, the coastal landscape, and places for people to enjoy and potentially provoke thought and reflection on how we live and develop with water. Allowing people to experience the landscape, and over time see the coastal wetlands transform in response to the changing water levels, can encourage awareness and an environmental ethic for developing land in a way that responds to and works with dynamic natural systems. It also helps shift the priority of a human-centric design to one that is more accommodating to the environment, one that also makes room for wildlife habitats, which are also impacted by sea level rise due to the limited space to migrate landward due to urban development.

Climate change will force city officials to make tough decisions in determining how to develop or redevelop the built environment to adapt to changing conditions. Society is becoming increasingly aware that the status quo for how cities have been built is no longer sustainable, and that significant changes need to be made to address climate change. In order to encourage a shift in how cities are developed more research needs to be done to consider alternative options to traditional hard infrastructure.

This practicum provides a landscape infrastructural approach for False Creek Flats. As a semi-protected area, it will not have the same impacts that more exposed areas will face. More research needs to be done to consider different contexts and conditions, as different sites and regions may require different or additional solutions.

As a case study for research and design, False Creek Flats has provided an opportunity to learn about the consequences of climate change, specifically in relation to sea level rise and precipitation. This site has also provided an opportunity to consider landscape-based solutions to address future water conditions while also design interventions that can provide a more enjoyable public realm as well as places for people to engage with the landscape.

With the False Creek Flats soon to be undergoing a significant transformation over the next number of years, the City of Vancouver should leverage this opportunity to make False Creek Flats more resilient to climate change and flooding, while also setting the standard for how development can occur to be more resilient to sea level rise and climate change.

Areas for Further Research

Due to time constraints and other limitations, this practicum project did not have the opportunity to engage and collaborate with local Indigenous groups to develop a design strategy for the False Creek Flats. However, as these lands are within the traditional territory of the Coast Salish peoples, it is important that any redevelopment that occurs within this area is done in consultation and collaboration with the Musqueam, Squamish, and Tsleil'waututh Indigenous people who have lived on these lands for thousands of years, and who are potentially able to share traditional knowledge of the False Creek Flats, and how people and the land have historically adapted to changing sea levels.

Additionally, this project would benefit from further research related to the remediation of contaminated soils in rail yards and other types of industrial lands. This research could also include an exploration of how landscape architecture can support the remediation of contaminated lands in the False Creek Flats, as this will need to be considered as the area is redeveloped.


SHOULD I BE WORRIED?

Appendix

A.1 Climate and Global Trends

- Climate Variability and Climate Change
- Global Trends

A.2 Climate Trends in British Columbia and Vancouver

- Trends and Indicators in British Columbia and the Metro Vancouver Region
- Maximum and Minimum Temperature
- Precipitation
- Snow Depth
- Glaciers
- Freezing and Thawing
- River Flow and Temperature
- Sea Level
- Sea Surface Temperature
- Growing Degree Days
- Heating and Cooling Requirements
- Human Heath

Figure A.0 - 1
Should I be worried? False Creek, Vancouver

A. 1 Climate and Global Trends

Climate Variability and Climate Change

Climate is different from weather as it relates to a time scale over an extended period, whether it be decades, centuries or even millennia. Weather, however, reflects the conditions that occur over a shorter period, such as the day to day conditions.

Climate usually references averages and extremes that relate to "air temperature, precipitation, humidity, sunshine, and storm frequency" (British Columbia Ministry of Environment, 2016, p. 48). Climate is also a combination of natural processes with properties such as surface temperatures; ocean and wind currents; water content in clouds, snow, and ice; the pressure and density of the oceans and atmosphere; and the salinity of the sea, among others (Ibid., p. 48). In general, the history of the earth has experienced climate fluctuation, in response to both climate change and climate variability (Ibid., p. 48). Climate variability is the result of natural fluctuations in the climate system. For example, British Columbia's climate is affected by natural processes that occur in the Pacific Ocean, including the El Nino Southern Oscillation and the Pacific Decadal Oscillation (Ibid., p. 48). During its warm phase, El Nino brings "warmer winter temperatures and less winter precipitation to BC" and La Nina brings "cooler and wetter winters" (Ibid., p. 48). There are also neutral phases where there is minimal effect on the global climate (Ibid., p. 48). The Pacific Decadal Oscillation (PDO) relates to the northern Pacific Ocean and sea surface temperatures. Like the El Nino Southern Oscillation, the PDO has a cool and a warm phase, but it is much longer with each period lasting for approximately 20 to 30 years at a time (Ibid., p. 48).

Climate change is associated with changing trends in climate over long periods. Although the global climate system has historically seen change, it is occurring now at an unprecedented rate. Climate change does happen simultaneously with natural variations occurring with climate, such as El Nino; however, it can also affect natural climate variations, as has been seen with El Nino with more intense and frequent events in recent years (Ibid., p. 49). Human activities are accelerating the rate of change, in large part due to the combustion of fossil fuels, generating greenhouse gases that are strongly correlated with increases in atmospheric temperature. Greenhouse gases also persist for long periods in the atmosphere, meaning that even if humans were to stop all greenhouse gas emissions, global warming would continue for many years to come (Ibid., p. 49).

The earth is experiencing global warming at an increasing rate, exposing the vulnerabilities of human and natural systems. Climate change is affecting various regions of the planet differently and causing more frequent and intense events such as droughts, wildfires, heat waves, cyclones, flooding, glacier retreat, and sea level rise. The frequency and effect of these changes are not only altering ecosystems, but they also have a rippling impact on people and the economy.

Global Trends

Many of the weather and climate events observed today are the result of global warming. In 2014, Intergovernmental Panel on Climate Change (IPCC) reported that in the previous 800 years in the Northern Hemisphere, the temperature at the Earth's surface reached its warmest during the period between 1983 and 2012 (IPCC, 2014, p. 40). With an increased amount of energy added to the climate system, the IPCC (2014, p. 40) concluded that the oceans absorbed 90% of this energy and only 1% by the atmosphere between 1971 to 2010.

Anthropogenic greenhouse gas has been a significant driver of climate change. The IPCC (2014, p. 44) reported that emissions reached their highest level between 2000 and 2010, with "carbon dioxide, methane, and nitrous oxide" reaching unprecedented levels in the last 800,000 years. Since 1750, carbon dioxide, methane, and nitrous oxide have increased by 40%, 15%, and 20% (Ibid., p. 44). Roughly half of the cumulative human-generated carbon dioxide emissions added to the atmosphere since 1750, were added in the last 40 years; during the same period, carbon dioxide contributed to about 78% of the total emissions (Ibid., p. 45).

The IPCC (2014, p. 46) reported that in 2010, more than a third of the total greenhouse gas emissions released came from the energy sector and 24% came from the agriculture, forestry and other land use sectors; "21% by industry; 14% by transport; and 6.4% by the building sector." Both global economic and population growth generate significant carbon dioxide emissions, due to fossil fuel consumption (Ibid., p. 46).

The global water cycle is affected by the different rates of precipitation and evaporation occurring in different regions of the earth, with some areas of the ocean becoming fresher and some more saline (Ibid., p. 40). The acidification of the sea also impacts ocean ecosystems. Since the industrial era, the ocean has absorbed increasing amounts of carbon dioxide, causing a decrease in the pH of the ocean's surface water and oxygen available in coastal waters (Ibid., p. 41). Warmer water temperatures affect the ventilation and oxygen solubility in oceans, also affecting fish habitats in the Pacific, Atlantic, and Indian Oceans (Ibid., p. 51).

A. 2 Climate Trends in British Columbia and Vancouver

Trends and Indicators in British Columbia and the Metro Vancouver Region

The temperature in British Columbia (BC) has increased, on average, 1.4°C per century since 1900, with the warmest period in the last 1400 years, occurring between 1983 and 2012 (British Columbia Ministry of Environment, 2016, p. 8). In British Columbia, most of the increases in warming temperatures are happening over winter, with most noticeable effects in the northern regions. Temperatures can affect the arrival and duration of seasons, which are dependent on climate, latitude, and altitude; however, coastal regions generally experience spring sooner than northern areas or areas in higher elevations, such as the mountains (Ibid., p. 9).

Temperature is an important indicator because it can be easily measured, observed and is a consistent indicator across various geographic regions and is a primary component of climate (Ibid., p. 9). In British Columbia, rising sea surface temperatures and precipitation influence increasing temperatures (Ibid., p. 9).

The impacts associated with increasing atmospheric temperatures are variable. Increased temperatures affect the length of time it takes for snow and ice to melt on lakes and rivers, affecting aquatic ecosystems and species sensitive to water temperatures (Ibid., p. 9). Faster snow and ice melt can also cause flooding, as well as allowing water and exposed land to absorb and retain the sun's energy. Warming temperatures allow vegetation to grow in areas that were previously too cold, which can be a benefit for agriculture in expanding opportunities for new crops; however, increasing temperatures also give room for pests to expand into new territories, posing a risk for plant and tree mortality (Ibid., p. 9). Increasing temperatures can also increase evaporation and decrease soil moisture, which can cause soil erosion and dust storms and increase the melting of snowpacks - lessening the water available for hydroelectric dams and reservoirs for drinking water, affecting water quality, and warming temperatures that reduce the winter season can affect outdoor winter activities and tourism, such as skiing for resorts (Ibid., p. 9).

Although a variety of factors can influence air temperatures, such as El Nino, the atmosphere and ocean currents, the trends observed during the 20th and 21st century are beyond natural variability (Ibid., pp. 8 - 10). The IPCC concluded that over the last 50 years, increases in atmospheric greenhouse gases have caused global warming, which is primarily caused by humans, from the "burning of fossil fuels and clearing … land for agriculture" (Ibid., pp. 8-10).

Increasing temperatures are also causing glaciers, and the Arctic, Greenland and Antarctic ice sheets to melt. Between 1979 and 2012, the Arctic ice sheet decreased by approximately 3.5 to 4.1% per decade, whereas the Antarctic ice sheet has decreased in mass by 1.2 to 1.8% (IPCC, 2014, p. 42). Both glacier mass loss and ocean thermal expansion have resulted in 75% of the mean sea level rise from the 1970s (Ibid., p. 42). As sea level rise increases, coastal communities are prone to more flood risks. Past inter-glacial periods can provide insight as to how much the global sea level can rise. During the last inter-glacial period, roughly 129,000 to 116,000 years ago, the global mean sea level rise was approximately 5 metres higher, with the Greenland ice sheet contributing to about 1.4 to 4.3 metres to the increased sea level (Ibid., pp. 42-44). During this period, IPCC (2014, p. 44) reports that the high-latitude surface temperatures were approximately 2°C warmer.

Increased temperatures have also reduced overall snow cover and thickness of the permafrost in the Northern Hemisphere (Ibid., p. 42). The reduction in snow cover, glaciers, and ice sheets has decreased the albedo effect, resulting in further energy absorption and increased surface temperatures.

Changing precipitation is affecting the hydrologic system, affecting water quality and quantity in different regions, and climate change is altering the geographic ranges of terrestrial and aquatic species, where they migrate, population levels, and how they interact with each other (Ibid., p. 51). With the increased drought, wildfires, and tree pests have also caused tree mortality in many regions throughout the world with some likely due to climate change (Ibid., p. 51).

Figure A.2 - 1
View of Vancouver from the Cypress Bowl Lookout, West Vancouver

Maximum and Minimum Temperature

Another indicator of climate change is the minimum and maximum daily temperatures. In British Columbia, the annual day-time temperatures increased on average 0.7 °C over 113 years (British Columbia Ministry of Environment, 2016, p. 11). Across British Columbia, the most change is occurring in the northern regions. Further, the annual night-time temperatures have also increased across the province, on average by 2°C over 113 years (Ibid., p. 12). The southern regions have experienced some noticeable trends, with the Georgia Depression observations indicating an increase of 1.2°C in the winter and spring, 1.5°C in the summer and 0.8°C in the fall (Ibid., p. 12).

Increased day-time and night-time temperatures are decreasing the temperature range during the average day. The increased day-time and night-time temperatures are also extending the freeze-thaw cycle in mid and high-latitude areas, as well as expanding growing conditions for pests and vegetation, and reducing heating costs. However, increasing night-time temperatures affect humans and other species sensitive to heat stress, where it becomes difficult to cool down overnight (Ibid., p. 13).

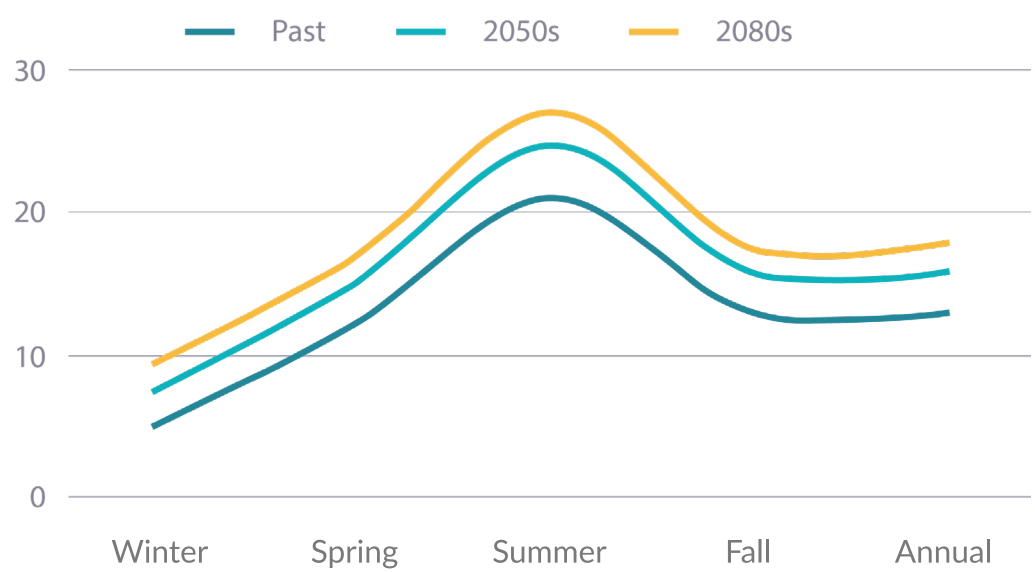
In Metro Vancouver, the most considerable change in warmer temperatures will be in the summer months, with daytime high temperatures increasing by 3.7°C by the 2050s and 6°C by the 2080s (Metro Vancouver, 2016, p. 8). Night-time lows will also increase, with projections estimating an overall increase of 3°C by the 2050s (Ibid., p. 8). Based on projected climate models of the increasing day-time high temperatures in the summer months, Vancouver could become warmer than present-day San Diego by the 2050 (Ibid., p. 22). Temperatures are also likely to increase by approximately 3°C in the Metro Vancouver region by the 2050s (Ibid., p. vi).

By the 2050s, the Metro Vancouver region may see the warmest winter temperatures rise to 15°C, and as high as 18°C by the 2080s (Ibid., p. 31). The coldest temperatures will also see an increase from -13°C to -8°C by the 2050s, and -5°C by the 2080s (Ibid., p. 31).

The Metro Vancouver region will also experience a decrease in the number of frost days (the days where temperatures are below 0°C) from an average of 79 days, to 33 by the 2050s and 17 by the 2080s; however, lower lying areas may be entirely frost free based on future projections (Ibid., p. 32).

Projected Average Daytime Temperature (°C)

Metro Vancouver Region



Season	Past (°C)	2050s (°C)	2080s (°C)
Winter	5	7.5	9.4
Spring	2	14.9	16.7
Summer	21	24.7	27
Fall	3	15.8	17.5
Annual	13	15.9	17.9

Table A.2-1
Projected average daytime temperature for Metro Vancouver region (based on Metro Vancouver, 2016, p. 8).

Precipitation

Precipitation as an indicator of climate change monitors the annual daily rainfall. Overall, the increase in average yearly precipitation across British Columbia has been 12% over 113 years, and in the Georgia Depression precipitation increased by 14% during the same period (British Columbia Ministry of Environment, 2016, p. 14). Winter precipitation observations did not indicate significant trends province-wide; however, the Georgia Depression saw an increase during the spring season by 23% per century (Ibid., p. 14).

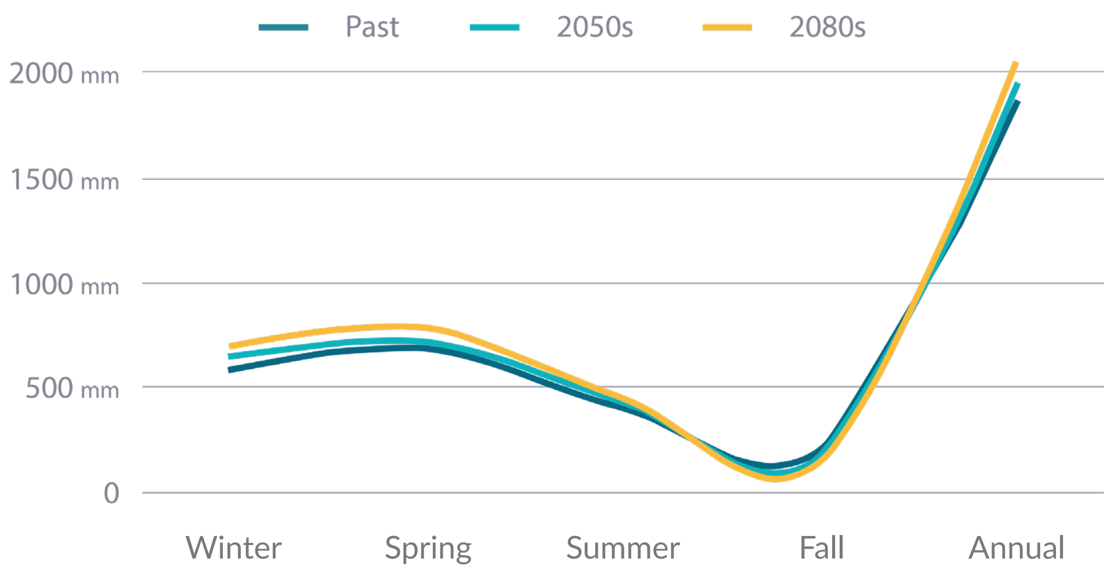
Although precipitation can be a significant indicator of climate change, in British Columbia topography and natural climate variability influence precipitation rates. For example, mountain slopes experience more precipitation because of the prevailing westerly winds carrying moisture from the Pacific Ocean. As climate change continues, British Columbia will experience warmer temperatures and more precipitation, and the long-term modifications will impact human and natural systems. More water from precipitation may recharge aquifers, increase soils moisture, sustain plant growth, and maintain wetlands and marshes (Ibid., p. 15). For people, an increase in precipitation will supply hydroelectric power generation, irrigation, and household water use, but can also increase flooding and place increasing pressure on infrastructure in some areas. Areas with combined stormwater and sewage systems will have reduced capacity, causing outflows into nearby water systems, degrading water quality (Ibid., p. 15). Winter precipitation can help winter tourism economies, such as ski resorts, but may also increase demands for road maintenance and can increase the number of accidents on roads (Ibid., p. 15). Increased winter precipitation can also increase the spring runoff into nearby hydrologic systems, affecting water quality in aquatic ecosystems (Ibid., p. 15).

Projections indicate that the Metro Vancouver region will experience wetter winters and drier summers. Projections estimate a 5% increase in the total annual precipitation by the 2050s and an 11% increase by the 2080s; however, this increase will be distributed unevenly throughout the year (Metro Vancouver, 2016, p. 12). The most considerable change will occur in the fall season, with an increase of 11% by the 2050s, and 20% by the 2080s (Ibid., p. 12). There will be a decline of precipitation in the summer season of 19% by the 2050s, and 29% by the 2080s (Ibid., p. 12). The number of days that the Metro Vancouver region will receive less than 1 mm of rain is expected to increase from 21 days to 26 days by the 2050s, and 29 days by the 2080s (Ibid., p. 18). During these dry spells, reservoirs will not recharge; however, projections suggest that significant increases in extreme rainfall in the 99th percentile will bring more frequent and intense storms (Ibid., p. 19).

In the Metro Vancouver region, it is expected that both low lying areas and high elevations will see an increase in 1-in-20 wettest day events (Ibid., p. 20). On average, the Metro Vancouver region has seen approximately 154 mm of rain during the month of January; however, by the 2080s there is a 5% chance this amount of rain could occur during a single day event (Ibid., p. 20).

Projected Seasonal and Annual Precipitation

Metro Vancouver Region



Season	Past (mm)	2050s (mm)	2080s (mm)	2050s Percent Change (%)	2080s Percent Change (%)
				Average	Average
Fall	580	642	693	11	20
Winter	683	714	780	5	14
Spring	400	430	447	8	12
Summer	206	168	147	-19	-29
Annual	1869	1953	2068	5	11

Table A.2-2
Projected seasonal and annual precipitation for the Metro Vancouver region (based on Metro Vancouver, 2016, p. 12).

Snow Depth

This indicator monitors the “changes in snow depth and snow water equivalent (SWE), the amount of water that is contained in the snowpack” (British Columbia Ministry of Environment, 2016, p. 17). The trends across the province are not consistent; however, the snow depth change in the Georgia Depression has lowered 6% per decade between 1950 and 2014 (Ibid., p. 17).

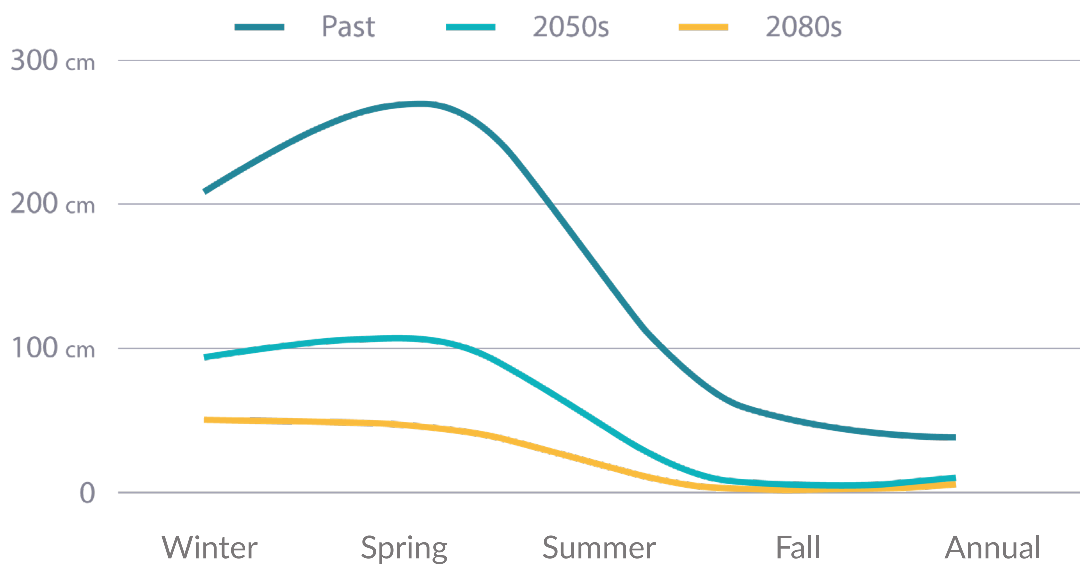
Many of the rivers and streams in BC experience an influx of water in the spring and summer seasons, being primarily fed by spring melt. The added water to the hydrologic systems affects aquatic species that are sensitive to water temperatures, and also affects the water supply for irrigation, hydroelectric dams, industry, and household water use.

Snow density affects how the snow melts. Denser snow melts faster, due to it being closer to its melting point (Ibid., p. 18). Increased rainfall on snow, can increase the density of the snow, and result in rapid melting and flooding (Ibid., p. 18). As temperatures continue to rise, winter precipitation will become more saturated (Ibid., p. 18).

Three mountain reservoirs supply drinking water to the Metro Vancouver regions, including Capilano, Seymour, and Coquitlam (Metro Vancouver, 2016, p. 15). Precipitation and snowmelt supply water for these watersheds. As such, changes in precipitation will impact the water supply of the reservoirs (Ibid., p. 15). In the spring, the snowpack is usually at its highest, after the snow has accumulated over the winter and early spring season (Ibid., p. 16). Projections indicate that the winter snowpack, averaged across the three watersheds, will decline significantly in future years by 56% by the 2050s, and 77% by the 2080s (Ibid., p. 16). As the snowpack levels in the spring continue to decrease, the snow line will recede further up the mountains (Ibid., p. 16). Monitoring the number of ice days can help determine snow formation and retention. In the Metro Vancouver region, projections anticipate that the number of ice days will see a decrease from an average of 12 days to 4 days by the 2050s, and two days by the 2080s (Ibid., p. 34).

Seasonal Snowpack Depth

Metro Vancouver Region



Season	Past (cm)	2050s (cm)	2080s (cm)	2050s Percent Change (%)	2080s Percent Change (%)
				Average	Average
Fall	37	10	5	-75	-87
Winter	208	93	49	-56	-77
Spring	266	102	43	-62	-84
Summer	73	11	3	-86	-97

Table A.2-3
Projected seasonal snowpack depth (watershed average) for the Metro Vancouver region (based on Metro Vancouver, 2016, p. 16).

Glaciers

Climate-driven changes affect the advance and retreat in glaciers. Glacier retreat is most affected by temperature increase over a long timespan occurring over decades and centuries (British Columbia Ministry of Environment, 2016, p. 20). There are two indicators used to observe trends related to climate change and glaciers, including the difference in the area of glacier coverage, and the change in the total volume of the glacier ice (Ibid., p. 20). In British Columbia, the glaciers retreated 2,525 km^2 between 1985 and 2000 and lost 21.9 km^3 of ice each year during the same period (Ibid., pp. 20-21). The distribution of this change has not been equal across the province, as some areas tend to have more glaciers than others, such as the glaciers in the Coast and Mountains ecoprovince. In the Georgia Depression ecoprovince, the volume of glacier ice decreased by 3 km^3 and 34%, most of which occurred on Vancouver Island (Ibid., p. 20).

Glaciers impact systems and human activities that depend on water, including freshwater and estuarine ecosystems (Ibid., p. 21). The spring/summer runoff feeds rivers and streams, with high water flow in the spring and early summer. Depending on the rate of the melting, glaciers can add a significant amount of water to rivers and streams, which can provide short-term benefits to systems and people that depend on water, such as hydroelectric dams (Ibid., p. 21). However, changes can also impact ecosystems by affecting water temperature or damage to fish habitats due to the turbidity of the water or riparian areas (Ibid., p. 21). Over time, less water from glaciers may be available and will reduce water volumes in rivers and streams.

Figure A.2 - 2
View of Mount Rundle from Two Jack Lake in Banff, Alberta

Freezing and Thawing

The days and times of the year in which rivers and lakes freeze and thaw are indicators for climate change. Tracking freeze and thaw events is done by monitoring when rivers and lake ice melt; when they are ice-free; when they first start to freeze; and the time when they are completely frozen (British Columbia Ministry of Environment, 2016, p. 22). Overall, British Columbia has seen earlier thaw times in the spring and later freezing events in the fall; however, the trends in British Columbia vary in comparison to global trends, suggesting that changes seen locally are more probably due to climate variability (Ibid., p. 22). Despite this, changes in the freeze and thaw times impact ecosystems primarily through water temperatures.

During the winter, water is usually warmer at the bottom of the lake as compared to summertime, when it is colder than the surface water. During winter and summer, the water is stratified, reducing the movement and circulation of water, and keeping temperatures consistent in each stratification (Ibid., p. 23). With earlier thaw times, and later freeze times, the water in rivers and lakes may mix more causing changes in the water temperature that aquatic species are not accustomed to, and potentially affecting their life cycles or growing seasons that probably have specific timing points that align with thawing and freezing events (Ibid., p. 23). Furthermore, changes to the thermal regimes of lake water can also impact the level of dissolved oxygen in the water (Ibid., p. 23).

Although in British Columbia the change in the freezing and thawing times is probably attributable to climate variability, the timing is affected by atmospheric temperatures, "cloudiness, solar radiation, wind speed, humidity, precipitation, the depth and composition of snow on top of the ice, and water temperature" (Ibid., p. 23).

Figure A.2 - 3
Athabasca River in Whitecourt, Alberta

River Flow and Temperature

Another indicator of climate change is monitoring the timing and volume of river water. Timing is observed by measuring the dates when the annual volume of water from each river has passed, whereas "volume is monitored by the seasonal minimum, maximum, and mean flow[s]" of the river (British Columbia Ministry of Environment, 2016, p. 24). There are variations in the trends in British Columbia due to the factors that influence these indicators, which include: "changes in temperature, precipitation, and evapotranspiration" (Ibid., p. 25). It also depends on the water regime of a basin, its location, size, and elevation, and whether rainwater or snowmelt feed it, and how much area is covered by glaciers (Ibid., p. 25).

In British Columbia, there has been variation in the river flow timing with a general trend of decline for mean annual river flow between 1912 and 2012, with a decrease by 16% in the Fraser River at Hope (Ibid., p. 25). This measure is significant due to the watershed catchment area of the Fraser River (Ibid., p. 25). Increasing temperatures are a likely contributor as, during this monitoring period, precipitation only had a 3% decrease per century, and was not found to be statistically significant (Ibid., p. 25). Warmer temperatures increase evapotranspiration, reducing water supply to streams.

As identified by other indicators, changes in river flow and temperature can affect aquatic ecosystems, as well as communities that depend on water supply. Increasing temperatures in the winter have been observed across the province, providing less winter precipitation as snow and earlier snowmelt times, which also affect runoff to rivers and streams (Ibid., p. 26). Reduced water supply does have impacts on agriculture for irrigation, hydroelectric power generation, industry, and communities already short of water, such as those in the Okanagan area (Ibid., p. 26).

Measuring river temperature is necessary because it has implications for aquatic health. In British Columbia, the Fraser River at Hell's Gate is monitored and has been observed to warm at an approximate rate of 2.2°C more per century, although the data this observation is from is between the years 1953 and 1998 (Ibid., p. 27). This temperature change is significant as the Fraser River travels "1,370 km from its headwaters in the Rocky Mountains to the Pacific Ocean," and is a major migratory route for Canadian sockeye salmon (Ibid., p. 27). Increasing river temperatures affect the fitness, survival and reproduction success of salmon, and as a consequence also affect predatory species, such as bald eagles, bears, and communities that depend on salmon as a food and nutrient source (Ibid., p. 27). As river temperatures continue to rise, this will pose additional risks for salmon, as they are currently at a moderate-high risk of extinction (Ibid., p. 28).

In the long term, the "distribution of salmon and other cold water species" will likely expand to northern areas and higher altitude lakes (Ibid., p. 28). As reported by the British Columbia Ministry of Environment (2016, p. 28), a 4°C increase in atmospheric temperatures is "projected to expand the ranges of the smallmouth bass and yellow perch" in northern regions by approximately 500 kilometres.

As river temperature changes in British Columbia can signal changes to climate, variations in the natural climate, such as seasonal and annual variations, and more significant events such as El Nino and La Nina, can also influence temperatures. Projections indicate that river temperatures will increase most significantly in interior British Columbia (Ibid., p. 28). Although distant from the Pacific Ocean, the region of the interior of BC contains the majority of rivers and streams supplying water to the Fraser River system (Ibid., p. 28).

River temperature is also slightly influenced by land use, as hydroelectric stations, industry, and agriculture tend to reduce vegetation, exposing the surface of adjacent rivers and streams to more of the sun's heat (Ibid., p. 29).

Sea Level

Sea level is a significant indicator of climate change for coastal communities and is monitored by measuring the changes in average sea level relative to the adjacent land. Globally, sea level has risen at a rate of approximately 17 centimetres per century, and since the early 1990s, it has grown to 3.2 millimetres per year (British Columbia Ministry of Environment, 2016, p. 31). As climate change has resulted in global increases in sea level rise, isostatic rebound, the vertical upward movement of land as a result of glacial retreat from thousands of years ago; tectonic shifts; subsidence where land is sinking; and natural climate variability from events like El Nino also influence local trends (Ibid., p. 31).

There are four tide gauges along the British Columbia coast that have collected records between 1910 and 2014 (Ibid., p. 31). Between this time, the average relative sea level rose "13.3 centimetres per century at Prince Rupert, 6.6 centimetres at Victoria, and 3.7 centimetres at Vancouver" (Ibid., p. 31). However, the average relative sea level lowered at "Tofino at the rate of 12.4 centimetres per century" (Ibid., p. 31). The variation at these four locations is mostly due to different rates of vertical land motion. For example, Vancouver Island has risen "25 centimetres per century, while the vertical" movement at Prince Rupert has not shown any significant changes (Ibid., p. 31).

Increased sea level will pose risks to low-lying areas, and will increase the frequency of flooding, while also threatening coastal wetlands, beaches, and cultural places of significance (Ibid., p. 31). It will also place pressures on storm and sewer infrastructure and may contaminate aquifers that supply domestic and agricultural uses with water (Ibid., p. 31). Soils for agriculture may become too saline, even before entirely inundated by sea water (Ibid., p. 31). Damage from "high-water events, such as king tides" and storm surges will become more frequent, damaging buildings along waterfronts and will reduce shore stability due to erosion (Ibid., p. 32). With a significant amount of land within one metre of sea level, the Fraser River delta is particularly vulnerable to sea level rise and the risks it poses (Ibid., p. 32).

Sea level rise is impacted by increasing atmospheric temperature, because as water temperatures increase it also expands in volume. Projections anticipate that thermal expansion will be a significant contributor to increasing sea level rise, as will increased water volume in the oceans due to the melting of glaciers, ice caps, and ice sheets (Ibid., p. 32). Projections from climate models anticipate that the "global mean sea level" will increase by "26 to 98 centimetres by 2100" although it will not be distributed evenly and will depend on the currents of the ocean moving and circulating the added heat and mass (Ibid., p. 32). Due to the oceans slow response to thermal expansion and climate change, even with efforts to minimize greenhouse gases, sea levels will continue to rise for hundreds of years to come (Ibid., p. 32), forcing coastal communities to take action to adapt to changing conditions.

Sea Surface Temperature

Sea surface temperature is also an indicator of climate change as increases in the atmospheric temperature influence it. In British Columbia, annual sea surface temperature has increased significantly, with the most influential trends in the summer; however, areas with tidal mixing with freshwater outlets can minimize local effects, such as areas near the Fraser River Delta (British Columbia Ministry of Environment, 2016, p. 33). The IPCC has suggested, "that global sea surface temperature has increased at a rate of 1.1°C per century between 1971 and 2010" (Ibid., p. 34).

These trends correlate with the data for the west coast of Vancouver Island, although it is the area along the British Columbia coastline most exposed to the Pacific Ocean (Ibid., p. 34). At Entrance Island, on the east coast of Vancouver Island, the sea surface temperatures increased in winter to roughly 2.2°C, and the average annual temperature rose to approximately 1.4°C per century (Ibid., p. 34).

Sea surface temperature, salinity, and density of the ocean water influence the health of marine ecosystems. High surface temperatures affect salmon reproductive success, by forcing salmon to shift their distribution patterns and migration routes (Ibid., p. 34). Ocean temperature affects ocean productivity, as increases in temperature impacts the water column and the mixing of water, which provides nutrients to plants and animals (Ibid., p. 34). The upper 100 metres of the ocean is the most productive zone, where sunlight penetration allows for photosynthesis for microscopic plants, and a food source for microscopic animals which provide food for larger fish and the food chain (Ibid., p. 34). Phytoplankton grows mostly in the spring and summer by taking up most of the nutrients. The replacement of nutrients takes place in the fall through a mixing process encouraged by tides, waves, storms, and prevailing winds (Ibid., p. 34). The ocean is most productive when deeper mixing occurs; however, the stability of the oceans water column is affected by sea temperatures. It becomes more difficult for the water to mix as the sea surface temperature is warmer, as the "surface sits more securely on top of the deeper water" (Ibid., p. 35).

Climate variability from El Nino and La Nina also affect ocean productivity. During El Nino, the sea surface is warmer and the water column is more stable, and mixing will typically occur in the first 100 metres (Ibid., p. 35). During a La Nina event, with colder than average temperatures, mixing can occur as far down as 140 metres (Ibid., p. 35). With increasing sea surface temperatures, projections indicate that a more stagnant ocean near the coasts may occur, affecting nutrient supply for marine ecosystems (Ibid., p. 35). Projections anticipate that the earth "will continue to warm and that the average global sea surface temperature will increase by 0.6°C to 2°C in the top 100 m by the end of the 21st century" (Ibid., p. 35). In British Columbia, the west coast of Vancouver Island will likely reflect global trends, although precipitation and freshwater runoff will more likely influence sea surface temperatures in the Georgia Basin (Ibid., p. 35).

Growing Degree Days

An indicator related to vegetation and climate change is Growing Degree Days, which observes the difference in “heat energy available for plant growth” (British Columbia Ministry of Environment, 2016, p. 40). Both plants and invertebrates can enter new phases of development based on certain thresholds of heat energy, which is related to their “physiological time” identified in “degree days” (Ibid., p. 40). Development is faster when temperatures increase, and each species has its minimum temperature threshold for growth to occur (Ibid., p. 40). Generally, agrologists will relate the heat requirements of a plant group to an average temperature of 5°C, where the Growing Degree Day is the difference between the average daily temperature and 5°C (Ibid., p. 40). If the average daily temperature is 12°C, this will result in seven additional Growing Degree Days to the annual metric (Ibid., p. 41).

British Columbia overall saw an average increase of 190 Growing Degree Days, aligning with increasing atmospheric temperatures trends seen across the province (Ibid., p. 40). The Georgia Depression, Coast and Mountains, and Sub Boreal Interior ecoprovinces saw the highest increase in Growing Degree Days with an average increase of 220 Growing Degree Days (Ibid., p. 40).

An increase in the Growing Degree Days may allow for new crops, provided that the soil fertility and moisture, and light conditions, are also sufficient. The increase in Growing Degree Days also means that more pests may enter the region (Ibid., p. 41). Certain crops that currently exist could be at risk if they are unable to tolerate the additional heat energy and increased temperatures, based on their physiology. Projections expect that Growing Degree Days will continue to rise, as temperatures increase - which is expected to increase by 2.7°C by 2080 (Ibid., p. 41).

In the Metro Vancouver region, the growing season has seen an average of 252 days and 1738 Growing Degree Days (Metro Vancouver, 2016, pp. 26-28). Projections indicate that the growing season will increase by 45 days by the 2050s, and 56 days by the 2080s; the Growing Degree Days will increase by 47% by the 2050s, and 82% by the 2080s (Ibid., pp. 26-28). Higher elevations in the mountains will see a greater percentage change, but the larger absolute change will occur in the lower elevations (Ibid., p. 28).

Heating and Cooling Requirements

Another indicator of climate change that is influenced by changes in atmospheric temperatures is the measurement of Heating Degree Days and Cooling Degree Days (British Columbia Ministry of Environment, 2016, p. 44). A Heating Degree Day is the measurement of the outdoor temperature colder than 18°C, whereas a Cooling Degree Day is the difference in outdoor temperature higher than 18°C (Ibid., p. 44). The measurement of heating and cooling requirements relates to the threshold of when people generally turn on heating or cooling systems (Ibid., p. 45).

In BC, the rate of Heating Degree Days decreased by 600 per century, between 1900 and 2013 (Ibid., p. 44). Northern BC observations indicated the most significant decrease in Heating Degree Days, and the rate fell by 310 Heating Degree Days in the Georgia Depression ecoprovince (Ibid., p. 44). The Southern Interior ecoprovince observed the highest rate of change for Cooling Degree Days, at 25 Cooling Degree Days per century (Ibid., p. 44). The Georgia Depression and the Southern Interior Mountains had the second highest rates, at an increase of 21 Cooling Degree Days per century (Ibid., p. 44).

This information is particularly vital to the energy sector, as it looks towards annual figures for Heating Degree Days to project energy demands, especially during cold temperatures. Cold Degree Day figures can also help project energy needs, as people tend to use air conditioning systems that depend on electricity; although energy demands for cooling in BC is not as significant as it is for heating (Ibid., p. 45). Projections anticipate that energy needs for cooling will increase as trends for temperature rise continues (Ibid., p. 45). Increases in surface temperature also impact heating and cooling requirements, although surface temperatures will vary depending on the location and context (Ibid., p. 45). Climate models suggest that in the future it will take more energy to cool buildings "in the Southern Interior, Georgian Depression and Southern Interior Mountains," as evening temperatures will not be cold enough to reduce building temperatures overnight (Ibid., p. 45).

In the Metro Vancouver region, there has been an average of 49 Cooling Degree Days, although projections estimate a substantial increase of 380% by the 2050s and 784% by the 2080s (Metro Vancouver, 2016, p. 29). The projections also suggest that lower lying areas in the Metro Vancouver region will exceed the cooling demands Kamloops currently experiences, and more than San Diego by the 2080s (Ibid., p. 29). Further, these projections indicate that the heating degree days will decrease by 25% by the 2050s, and 40% by the 2080s (Ibid., p. 34).

Human Health

Climate change can impact human health in a variety of ways. As temperatures rise, this can pose heat-related and respiratory illness (British Columbia Ministry of Environment, 2016, p. 46). In urban areas, buildings and pavement retains heat longer, and create conditions often referred to as the urban heat island effect. Additional heat due to warmer temperatures can increase incidents of “heat stroke, dehydration, and cardiovascular and respiratory illnesses” (Ibid., p. 46). Smog in larger cities with more emissions from vehicles and industry, such as Vancouver, will become more problematic as ground-level ozone will occur more frequently and more quickly as temperatures rise (Ibid., p. 46). Ground-level ozone can also cause respiratory problems for those who suffer from asthma and lung disease (Ibid., p. 46).

Water contamination becomes more problematic with sea level rise and increased precipitation. Low lying areas may be inundated with salt water, potentially carrying chemicals and organisms with disease with it, while extreme rain events will burden stormwater and sewer infrastructure, which can increase contamination (Ibid., p. 46). Further, the concentration of contaminants could become worse during times of water shortages (Ibid., p. 46). Increased precipitation and water temperatures can also bring water-borne diseases, such as red tide, a shellfish disease that “is caused by a toxic algae that grows in warm coastal waters during the summer” (Ibid., p. 47). People that consume shellfish contaminated with red tide can become ill (Ibid., p. 47).

Increased temperatures also allow species to expand their ranges, including those that may be “vectors” carrying human diseases (Ibid., p. 47). In BC, “vector” carrying animals often includes rodents, ticks, and mosquitoes. Weather-related accidents that may cause human injury and death may also rise, as climate change increases the incidents of “flooding, landslides and extreme weather-related events” (Ibid., p. 47).

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Figures Reference List

Figure 0.1 - 1
Pihooja, K., 2019. *False Creek Flats Context Map*. [digital image]

Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Pihooja, K., 2016. *CN Rail behind Terminal Avenue*. [photograph]

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Matthews, J. S., Major, 1904. *Shoreline area of False Creek flats (sic)*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/shoreline-area-of-false-creek-flats> [Accessed on 23 February 2019]. (Public Domain)

Figure 1.1 - 1
Pihooja, K., 2018. *Historic shoreline and lost streams of Vancouver*. [digital image] Based on:

Vancouver Public Aquarium Association, 1978. *Vancouver's old streams*. [digital image] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/vancouvers-old-streams> [Accessed on 23 February 2019].

Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, n.d. *City Streets Data Package*. [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

Figure 1.1 - 2
Matthews, J. S., Major, 1904. *Shoreline area of False Creek flats (sic) (2)*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/shoreline-area-of-false-creek-flats-2> [Accessed on 23 February 2019]. (Public Domain)

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Matthews, J. S., Major, 189-. *View of Leamy and Kyle Sawmill on False Creek*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/view-of-leamy-and-kyle-sawmill-on-false-creek> [Accessed on 23 February 2019]. (Public Domain)

Figure 1.1 - 4
Vancouver World Printing and Publishing Company, 1898. *Panoramic view of the City of Vancouver, British Columbia, 1898*. [Cartographic material] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/panoramic-view-of-city-of-vancouver-british-columbia-1898-2> [Accessed on 23 February 2019]. (Public Domain)

Figure 1.1 - 5
Matthews, J. S., Major, 1889. *Vancouver B.C. from the South*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/vancouver-b-c-from-south> [Accessed on 23 February 2019]. (Public Domain)

Figure 1.1 - 6
Matthews, J. S., Major, 190-. *Central Park Line in the Early Days*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/central-park-line-in-early-days> [Accessed on 23 February 2019]. (Public Domain)

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Rand Brothers Real Estate Brokers, 1891. *Plan of the City of Vancouver. Western Terminus of the Canadian Pacific Railway*. [cartographic material] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/plan-of-city-of-vancouver-western-terminus-of-canadian-pacific-railway> [Accessed on 23 February 2019]. (Public Domain)

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Matthews, J. S., Major, 1917. *View of False Creek Flats east of Main Street*. [photograph] Vancouver, British Columbia: City of Vancouver Archives. Available at: <https://searcharchives.vancouver.ca/view-of-false-creek-flats-east-of-main-street-2> [Accessed on 23 February 2019]. (Public Domain)

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British Columbia Ministry of Environment, 2016. *Indicators of Climate Change for British Columbia 2016 Update*. [pdf file] Victoria, British Columbia: British Columbia Ministry of Environment. Available at: <https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/reporting/envreportbc/archived-reports/climate-change/climatechangeindicators-13sept2016_final.pdf> [Accessed on 18 May 2018].

Figure 1.2 - 2
Pihooja, K., 2018. *Soil Groups in Vancouver*. [digital image] Based on:

Virtual Soil Science Learning Resources, n.d. *Vancouver Soil Map*. [map data] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Pihooja, K., 2018. *10,000 years ago, Fraser Glaciation*. [digital image] Based on:

Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Pihooja, K., 2018. *Land compressed remains underwater*. [digital image] Based on:

Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Pihooja, K., 2018. *Whatcom-Scat soils.* [digital image] Based on:

Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

Figure 1.2 - 8
Pihooja, K., 2018. *Delta-Tsawwassen soils.* [digital image] Based on:

Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online image] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

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Pihooja, K., 2018. *Surficial geology, soils map, and soil descriptions of Vancouver*. [digital image] Based on:

City of Vancouver, 2016. *Integrated Stormwater Management Vision Principles and Actions Volume I - Vision, Principles & Actions Final Draft.* [pdf file] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/integrated-stormwater-management-vision-principles-and-actions-volume-1.pdf> (p. 14-15) [Accessed on 25 August 2018].

Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Pihooja, K., 2018. *Vancouver liquefaction potential.* [digital image] Based on:

City of Vancouver, 2013. *Earthquake Preparedness Strategy Update*. [pdf file] Vancouver, British Columbia: City of Vancouver. Available at: <https://council.vancouver.ca/20131203/documents/rr1.pdf> (p. 20) [Accessed on 25 February 2019].

Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre.* [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Pihooja, K., 2018. *Topographic relationships in the dry, maritime, Coastal Western Hemlock subzone*. [digital image] Based on:

Pojar, J., Kinka, K., and Demarchi, D., 1991. *Coastal Western Hemlock Zone*. In J. Pojar and D. Meidinger, ed. 1991. *Ecosystems of British Columbia: Special Report Series 6*. [pdf file] Victoria, British Columbia: British Columbia Ministry of Forestry. Available at: <https://www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.pdf> (p. 103) [Accessed on 23 July 2018].

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Created with:
City of Vancouver, Engineering Services, n.d. *City Streets Data Package*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

Figure 1.3 - 2
Pihooja, K., 2018. *Topography of False Creek Flats*. [digital image]

Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Vancouver Public Aquarium Association, 1978. *Vancouver's old streams*. [digital image] Vancouver, British Columbia: City of Vancouver Archives at: <https://searcharchives.vancouver.ca/vancouvers-old-streams> [Accessed on 23 February 2019].

Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, n.d. *City Streets Data Package*. [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

Figure 1.3 - 7
Pihooja, K., 2018. *Historic shoreline False Creek Flats*. [digital image] Based on:

Vancouver Public Aquarium Association, 1978. *Vancouver's old streams*. [digital image] Vancouver, British Columbia: City of Vancouver Archives at: <https://searcharchives.vancouver.ca/vancouvers-old-streams> [Accessed on 23 February 2019].

Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Pihooja, K., 2018. *Stormwater management areas and sewer network.* [digital image] Based on:

City of Vancouver, 2016. *Integrated Stormwater Management Vision Principles and Actions Volume I - Vision, Principles & Actions Final Draft.* [pdf file] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/integrated-stormwater-management-vision-principles-and-actions-volume-1.pdf> (p. 12-13) [Accessed on 25 August 2018].

Lees and Associates, Karen Hurley and Associates, Dayton and Knight Engineers, and Hudema Consulting Group, 2002. *Still Creek Rehabilitation and Enhancement Study.* [pdf file] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/still-creek-rehabilitation-enhancement-study.pdf> (p. v) [Accessed on 13 March 2019].

City of Vancouver, n.d. *Map of Musqueam Creek Watershed.* [digital image] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/home-property-development/musqueam-integrated-stormwater-management-plan.aspx> [Accessed on 13 March 2019].

Created with:
City of Vancouver, Engineering Services, n.d. *Storm mains.* [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, n.d. *City Streets Data Package.* [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre.* [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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City of Vancouver, n.d. *Wave Effect Zone, and Designated Floodplain (FCL 4.6m).* [map layer] Vancouver, British Columbia: City of Vancouver VanMap. Available at: <http://vanmapp.vancouver.ca/pubvanmap_net/default.aspx> [Accessed on 25 July 2018].

Created with:
City of Vancouver, Engineering Services, n.d. *Storm mains.* [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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WeatherStats, n.d. *Total Precipitation Monthly Data.* [online] WeatherStats. Available at: <https://vancouver.weatherstats.ca/charts/precipitation-monthly.html> [Accessed on 23 January 2019].

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WeatherStats, n.d. *Total Precipitation Monthly Data.* [online] WeatherStats. Available at: <https://vancouver.weatherstats.ca/charts/precipitation-monthly.html> [Accessed on 23 January 2019].

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City of Vancouver, 2016. *Integrated Stormwater Management Vision Principles* *and Actions Volume I - Vision, Principles & Actions Final Draft*. [pdf file] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/integrated-stormwater-management-vision-principles-and-actions-volume-1.pdf> (p. 10-11) [Accessed on 25 August 2018].

Created with:
City of Vancouver, Engineering Services, n.d. *City Streets Data Package*. [dwg file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] Vancouver, British Columbia: City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Pihooja, K., 2018. *Zoning of False Creek Flats - 2018*. [digital image] Based on:

City of Vancouver, n.d. *Zoning Districts*. [map layer] Vancouver, British Columbia: City of Vancouver VanMap. Available at: <http://vanmapp.vancouver.ca/pubvanmap_net/default.aspx> [Accessed on 25 July 2018].

Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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City of Vancouver, 2017. *False Creek Flats Area Plan*. [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/false-creek-flats-plan-2017-05-17.pdf> (p. 12) [Accessed on 4 September 2018].

Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Crooks, M., 2011. *King Tides Rule*. [digital image]. Available at: <https://blog.education.nationalgeographic.org/2014/01/31/king-tides-rule-coasts/> [Accessed on 23 June 2018].

Figure 2.1 - 2
Pihooja, K., 2018. *High and low tide relationship with the position of the moon in relation to the earth*. [digital image] Based on:

Crooks, M., 2011. *King Tides Rule*. [digital image]. Available at: <https://blog.education.nationalgeographic.org/2014/01/31/king-tides-rule-coasts/> [Accessed on 23 June 2018].

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Pihooja, K., 2018. *The orbit of the moon around the earth and the earth around the sun*. [digital image] Based on:

National Oceanic and Atmospheric Administration (NOAA), n.d. *What is a perigean spring tide?* [digital image]. Available at: <https://oceanservice.noaa.gov/facts/perigean-spring-tide.html> [Accessed on 23 June 2018].

Figure 2.1 - 4
Pihooja, K., 2018. *Semidiurnal Inequality*. [digital image] Based on:

Pugh, D, 2004. *Changing sea levels : effects of tides, weather and climate*. Cambridge, UK: Cambridge University Press. (p. 40)

Figures Reference List

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Pihooja, K., 2018. *Lunar characteristics that influence tidal patterns*. [digital image] Based on:

Pugh, D, 2004. *Changing sea levels : effects of tides, weather and climate*. Cambridge, UK: Cambridge University Press. (p. 31)

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Department of Fisheries and Oceans Canada, n.d. *Observed Water Levels Vancouver B.C (Observed water levels between December 1 - 31, 2018)*. [online] Available at: <http://www.pac.dfo-mpo.gc.ca/science/charts-cartes/obs-app/observed-eng.aspx?StationID=07735> [Accessed on 28 January 2019].

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Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report*. [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3 June 2018] (p. 18).

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Pihooja, K., 2019. *Walker Cell and La Nina*. [digital image] Based on:

James, S., and Stull, R., 2019. *The Walker Cell and ENSO*. [online] Available at: <https://www.eoas.ubc.ca/courses/atsc113/sailing/met_concepts/09-met-winds/9c-walker-cell-enso/> [Accessed 28 January 2019].

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Pihooja, K., 2019. *Walker Cell and El Nino*. [digital image] Based on:

James, S., and Stull, R., 2019. *The Walker Cell and ENSO*. [online] Available at: <https://www.eoas.ubc.ca/courses/atsc113/sailing/met_concepts/09-met-winds/9c-walker-cell-enso/> [Accessed 28 January 2019].

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Ausenco Sandwell, 2011a. *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper*. [online] Victoria, British Columbia: British Columbia Ministry of Environment. Available at: <http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/draft_policy_rev.pdf> (p. 2) [Accessed on 3 June 2018].

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Pihooja, K., 2018. *Storm sewers network and floodplain zone*. [digital image]. Based on:

City of Vancouver, n.d. *Wave Effect Zone, and Designated Floodplain (FCL 4.6m)*. [map layer] City of Vancouver VanMap. Available at: <http://vanmapp.vancouver.ca/pubvanmap_net/default.aspx> [Accessed on 25 July 2018].

Created with:
City of Vancouver, Engineering Services, n.d. *Storm mains*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer*. [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report*. [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3 June 2018] (p. 37).

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Northwest Hydraulic Consultants, 2014. *City of Vancouver Coastal Flood Risk Assessment Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf> [Accessed on 3 June 2018] (p. 91).

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Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3 June 2018] (p. 39).

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Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3 June 2018] (p. 40).

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Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3 June 2018] (p. 41).

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Rutgers Cooperative Extension, n.d. [Watson-Crampton Open Space Floodplain Restoration Plan]. [digital image] In: Rutgers Cooperative Extension, n.d. *In the Flood Zone: Floodplain Restoration in Residential Neighbourhoods damaged by Superstorm Sandy.* [online] Allegheny Society of American Foresters - New Jersey Division. Available at: <https://njforests.org/wp-content/uploads/2017/02/restoration.pdf> [Accessed 16 March 2019] (p. 24).

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Michael Van Valkenburgh Associates, Inc., n.d. [West Don Lands exposed to Hurricane Hazel equivalent flood extent]. [digital image]. Available at: <https://www.canadianarchitect.com/features/parks-and-regeneration/> [Accessed 16 March 2019].

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Michael Van Valkenburgh Associates, Inc., n.d. [West Don Lands protected (light blue) with flood protection landform]. [digital image]. Available at: <https://www.canadianarchitect.com/features/parks-and-regeneration/> [Accessed 16 March 2019].

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Michael Van Valkenburgh Associates, Inc., n.d. [Cross-section of the flood protection landform]. [digital image] Available at: <https://www.canadianarchitect.com/features/parks-and-regeneration/> [Accessed 16 March 2019].

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Rabich, Dietmar, 2016. *Hamburg, HafenCity, Bebauung am Sandtorkai -- 2016 -- 3036.* [photograph] Wikimedia Commons. Available at: <https://commons.wikimedia.org/wiki/File:Hamburg,_HafenCity,_Bebauung_am_Sandtorkai_--_2016_--_3036.jpg> (Creative Commons - CC BY-SA 4.0)

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Flor!an, 2013. *Flood Marco-Polo-Terrassen Hamburg HafenCity December 2013*. [photograph] Wikimedia Commons. Available at: <https://commons.wikimedia.org/wiki/File:Hochwasser_Marco-Polo-Terrassen_Hamburg_HafenCity_Dezember_2013.jpg> (Creative Commons - CC BY-SA 3.0)

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Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Created with:

ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Created with:
ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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ESRI (Environmental Systems Resource Institute), 2016. *Base Map Data Layer.* [ArcGIS digital image] ArcGIS 10.3, 2016. Redlands, California.

Google Earth, n.d. [Google earth imagery of False Creek Flats]. [digital image] Available at: <https://www.google.com/earth/> [Accessed on 25 January 2019].

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Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre*. [shp file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Engineering Services, 1999-2002. *Contour 1 metre.* [shp file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

City of Vancouver, Information Technology, GIS and CADD Services branch, 2008. *Building footprints 2009*. [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch,

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2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

Figure 4.5 - 5
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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm>

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[Accessed on 17 June 2017].

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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Plant information based on:
G.L. Williams & Associates Ltd. and Coast River Environmental Services Ltd., 2006. *Vancouver Port Authority Deltaport Third Berth Proposed Habitat Compensation.* [online] Vancouver, British Columbia: Vancouver Port Authority. Available at: <https://www.ceaa.gc.ca/050/documents/16097/16097E.pdf> [Accessed on 25 January 2019] (p. 10).

Water level relationship to plants based on:
Moffatt & Nichol, 2016. *Vancouver Fraser Port Authority Habitat Enhancement Program New Brighton Park Shoreline Habitat Restoration Project.* [online] Vancouver, British Columbia: Port of Vancouver. Available at: <https://www.portvancouver.com/wp-content/uploads/2016/04/2016-04-29-03-200-NBP-60-Percent-Design-Drawing-Package-Rev0.pdf> [Accessed on 25 January 2019] (p. 7).

Figure 4.6 - 1
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Created with:
City of Vancouver, Information Technology, GIS and CADD Services branch, 2009. *Building footprints 2009.* [dwg file] City of Vancouver Open Data Catalogue. Available at: <https://data.vancouver.ca/datacatalogue/index.htm> [Accessed on 17 June 2017].

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Text Reference List

Arlington Group Planning + Architecture Inc., 2013. *Sea Level Rise Adaptation Primer A Toolkit to Build Adaptive Capacity on Canada's South Coasts.* [online] Victoria, British Columbia: British Columbia Ministry of Environment. Available at: <https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/resources/slr-primer.pdf> [Accessed on 4 April 2018].

Armstrong, J., 1990. *Vancouver Geology*. [online] Vancouver, British Columbia: Geological Association of Canada. Available at: <https://www.gac-cs.ca/publications/JohnArmstrong_VancouverGeology.pdf> [Accessed on 13 January 2019].

Ausenco Sandwell, 2011a. *Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use Draft Policy Discussion Paper*. [online] Victoria, British Columbia: British Columbia Ministry of Environment. Available at: <http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/draft_policy_rev.pdf> [Accessed on 3 June 2018].

Australian Government Bureau of Meteorology, n.d. *Understanding ENSO*. [online video] Available at: <http://www.bom.gov.au/climate/enso/> [Accessed on 28 January 2019].

Barnard, P., et al., 2015. Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation. *Nature Geoscience*. [Online] 8 (10), 801–807.

Bostock, B. (2017). *Episode 57 - Blue Acres with Director Fawn McGee*. [online] Discover DEP Podcast. Available at: <https://njdep.podbean.com/e/episode-57-blue-acres-with-director-fawn-mcgee/> [Accessed on 22 October 2018].

British Columbia Ministry of Environment, 2016. *Indicators of Climate Change for British Columbia 2016 Update.* [online] Victoria, British Columbia: British Columbia Ministry of Environment. Available at: <https://www2.gov.bc.ca/assets/gov/environment/research-monitoring-and-reporting/reporting/envreportbc/archived-reports/climate-change/climatechangeindicators-13sept2016_final.pdf> [Accessed on: 20 June 2018].

Cherry, J., 2018. *Research Areas: Global Change Effects on Tidal Wetlands*. [online] Available at: <http://cherrylab.ua.edu/research.html> [Accessed on 10 February 2019].

City of Edmonton, 2014. *Low Impact Development Best Management Practices Design Guide Edition 1.1.* [online] Edmonton, Alberta: City of Edmonton. Available at: <https://www.edmonton.ca/city_government/documents/PDF/LIDGuide.pdf> [Accessed on 25 August 2018].

City of Vancouver, 2013. *Earthquake Preparedness Strategy Update*. [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://council.vancouver.ca/20131203/documents/rr1.pdf> [Accessed on 25 February 2019].

City of Vancouver, 2015. *Greenest City Action Plan 2020: 2015 - 2020.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/greenest-city-2020-action-plan-2015-2020.pdf> [Accessed on 25 January 2019]

City of Vancouver, 2016. *Integrated Stormwater Management Vision Principles and Actions Volume I - Vision, Principles & Actions Final Draft*. [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/integrated-stormwater-management-vision-principles-and-actions-volume-1.pdf> [Accessed on 25 August 2018].

City of Vancouver, 2016b. *Integrated Stormwater Management Vision Principles and Actions Volume II - Vision, Principles & Actions Final Draft.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/integrated-stormwater-management-vision-principles-and-actions-volume-1.pdf> [Accessed on 25 August 2018].

City of Vancouver, 2017. *False Creek Flats Area Plan.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/false-creek-flats-plan-2017-05-17.pdf> [Accessed on 4 September 2018].

Clague, J., and Turner, B., 2010. *Vancouver, city on the edge : living with a dynamic geological landscape*. Vancouver, BC: Tricouni Press.

Compass Resource Management Ltd. and Ebbwater Consulting, 2015. *City of Vancouver Coastal Flood Risk Assessment Phase II Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-phase-2-final-report-oct-2016-revision.pdf> [Accessed on 3

June 2018].

Davis, A., and McCuen, R., 2005. *Stormwater Management for Smart Growth.* [online] Boston, MA: Springer US.

Demarchi, D., 2011. *An Introduction to the Ecoregions of British Columbia. 3rd ed.* [online] Victoria British Columbia: British Columbia Ministry of Environment. Available at: <https://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/ecosystems/broad-ecosystem/an_introduction_to_the_ecoregions_of_british_columbia.pdf> [Accessed on 23 July 2018].

Dillon Consulting, 2005a. *Executive Summary.* In: Dillon Consulting, 2005. *Lower Don River West Remedial Flood Protection Project: Class Environmental Assessment Environmental Study Report.* [online] Toronto, Ontario: Toronto and Region Conservation Agency. Available at: <https://trca.ca/conservation/green-infrastructure/lower-don-river-west-remedial-flood-protection-project/environmental-assessment/> [Accessed on 28 November 2018].

Dillon Consulting, 2005b. *Description of Lower Don.* In: Dillon Consulting, 2005. *Lower Don River West Remedial Flood Protection Project: Class Environmental Assessment Environmental Study Report.* [online] Toronto, Ontario: Toronto and Region Conservation Agency. Available at: <https://trca.ca/conservation/green-infrastructure/lower-don-river-west-remedial-flood-protection-project/environmental-assessment/> [Accessed on 28 November 2018].

Dillon Consulting, 2005c. *Examination of Alternatives.* In: Dillon Consulting, 2005. *Lower Don River West Remedial Flood Protection Project: Class Environmental Assessment Environmental Study Report.* [online] Toronto, Ontario: Toronto and Region Conservation Agency. Available at: <https://trca.ca/conservation/green-infrastructure/lower-don-river-west-remedial-flood-protection-project/environmental-assessment/> [Accessed on 28 November 2018].

Dillon Consulting, 2005d. *Functional Design and Environmental Assessment.* In: Dillon Consulting, 2005. *Lower Don River West Remedial Flood Protection Project: Class Environmental Assessment Environmental Study Report.* [online] Toronto, Ontario: Toronto and Region Conservation Agency. Available at: <https://trca.ca/conservation/green-infrastructure/lower-don-river-west-remedial-flood-protection-project/environmental-assessment/> [Accessed on 28 November 2018].

Donald Luxton and Associates Inc., 2013. *Eastern Core Statement of Significance.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/statement-of-significance-false-creek-flats-2013-april.pdf> [Accessed 26 May 2016].

FEMA, 2015. *Mitigation Best Practice - 3 Years Long, 3 Years Strong: New Jersey's Successful Approach to Purchasing Homes along Sandy's Flooded Path.* [online] Washington D.C.: Department of Homeland Security. Available at: <https://www.fema.gov/media-library/assets/documents/111721> [Accessed on 22 October 2018].

G.L. Williams & Associates Ltd. and Coast River Environmental Services Ltd., 2006. *Vancouver Port Authority Deltaport Third Berth Proposed Habitat Compensation.* [online] Vancouver, British Columbia: Vancouver Port Authority. Available at: <https://www.ceaa.gc.ca/050/documents/16097/16097E.pdf> [Accessed on 25 January 2019] (p. 10).

Gutro, R., 2013. *Satellite Captures the Life and Death of Hurricane Sandy on Halloween.* [online] Available at: <https://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html> [Accessed on 25 October 2018].

HafenCity Hamburg GmbH, 2017. *Themes Quarters Projects.* [online] HafenCity, Hamburg: HafenCity Hamburg GmbH. Available at: <https://www.hafencity.com/upload/files/files/HafenCityProjekte_March_2017_english.pdf> [Accessed on: 19 December 2018].

Hall, P., and Falk, N., 2014. *Good Cities, Better Lives: How Europe Discovered the Lost Art of Urbanism.* New York, New York: Routledge.

Halverson, J.B., and Rabenhorst, T., 2013. Hurricane Sandy: The Science and Impacts of a Superstorm. *Weatherwise.* [Online] 66 (2), 14–23.

Hicks, S., 2006. *Understanding Tides.* [online] Washington D.C.: U.S. Department of Commerce National Oceanic and Atmospheric Service. Available

Text Reference List

at: <https://tidesandcurrents.noaa.gov/publications/Understanding_Tides_by_Steacy_finalFINAL11_30.pdf> [Accessed on 28 January 2019].

Herrington, S., 2016. Beauty: past and future. *Landscape Research*. [online] 41 (4), 441–449.

Hogan, M., 2016. *What is a Flood Protection Landform?* [online] Toronto, Ontario: Waterfront Toronto. Available at: <http://blog.waterfrontoronto.ca/nbe/portal/wt/home/blog-home/posts/what-is-a-flood-protection-landform> [Accessed on 25 November 2018].

Hughes, M., 2016. *Coastal waves, water levels, beach dynamics and climate change*. [online] Sydney, New South Wales: CoastAdapt, National Climate Change Adaptation Research Facility, Gold Coast. Available at: <https://coastadapt.com.au/sites/default/files/factsheets/T3I4_Coastal_waves.pdf> [Accessed on 28 January 2019].

Hurricanes: Science and Society, n.d. *Katrina Impacts*. [online] Available at: <http://www.hurricanescience.org/history/studies/katrinacase/impacts/> [Accessed on 7 February 2019].

IPCC, 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].* [online] Geneva, Switzerland: IPCC. Available at: <https://archive.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf> [Accessed on 26 May 2018].

IPCC, 2018. *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].* [online] Geneva, Switzerland: World Meteorological Organization. Available at: <https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf> [Accessed on 29 January 2019].

James, S., and Stull, R., 2019. *The Walker Cell and ENSO*. [online] Available at: <https://www.eoas.ubc.ca/courses/atsc113/sailing/met_concepts/09-met-winds/9c-walker-cell-enso/> [Accessed 28 January 2019].

Lynch, K., 1960. *The image of the city*. Cambridge, Mass: M.I.T. Press.

Landscape Performance Series, n.d. *Corktown Common*. [online] Available at: <https://www.landscapeperformance.org/case-study-briefs/corktown-common#/project-context> [Accessed on 25 November 2018].

Metro Vancouver, 2016. *Climate Projections for Metro Vancouver*. [online] Burnaby, British Columbia: Metro Vancouver. Available at: <http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ClimateProjectionsForMetroVancouver.pdf> [Accessed on: 20 June 2018].

Meyer, E., 2008. Sustaining beauty. The performance of appearance: A manifesto in three parts. *Journal of Landscape Architecture*. [online] 3 (1), 6–23.

Moffatt & Nichol, 2016. *Vancouver Fraser Port Authority Habitat Enhancement Program New Brighton Park Shoreline Habitat Restoration Project*. [online] Vancouver, British Columbia: Port of Vancouver. Available at: <https://www.portvancouver.com/wp-content/uploads/2016/04/2016-04-29-03-200-NBP-60-Percent-Design-Drawing-Package-Rev0.pdf> [Accessed on 25 January 2019] (p. 7).

NASA (National Aeronautics and Space Administration), 2015. *El Niño Conditions Are Growing Stronger*. [online] Available at: <https://earthobservatory.nasa.gov/images/86341/el-nino-conditions-are-growing-stronger> [Accessed on 28 January 2019].

NOAA (National Oceanic and Atmospheric Administration), 2017. *Salmon Returns and Ocean Conditions*. [online]. Available at: <https://www.nwfsc.noaa.gov/publications/documents/salmon-returns-ocean-conditions-2017.pdf> [Accessed on 28 January 2019].

North Carolina Climate Office, n.d. *Global Patterns: Pacific Decadal Oscillation*. [online] Available at: <https://climate.ncsu.edu/climate/patterns/pdo> [Accessed on 28 January 2019].

Northwest Hydraulic Consultants, 2014. *City of Vancouver Coastal Flood Risk Assessment Final Report.* [online] Vancouver, British Columbia: City of Vancouver. Available at: <https://vancouver.ca/files/cov/CFRA-Phase-1-Final_Report.pdf> [Accessed on 3 June 2018].

O'Donnell, J., 2017. Living shorelines: a review of literature relevant to New England Coasts. *Journal of Coastal Research.* [online] 33 (2), 435.

Pojar, J., Kinka, K., and Demarchi, D., 1991. *Coastal Western Hemlock Zone*. In J. Pojar and D. Meidinger, ed. 1991. *Ecosystems of British Columbia: Special Report Series 6.* [online] Victoria British Columbia: British Columbia Ministry of Forestry. Available at: <https://www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.pdf> [Accessed on 23 July 2018].

Port of Vancouver, 2018. *Guidelines – Shoreline Protection (Vancouver Harbour) Inspection, Maintenance, Design and Repair Version 1.0.* [online] Vancouver, British Columbia: Port of Vancouver. Available at: <https://www.portvancouver.com/wp-content/uploads/2018/10/2018-04-Shore-Protection-Guidelines-Inspection-Maintenance-Design-and-Repair-v1.0.pdf> [Accessed on 12 January 2019].

Pratolongo, P., Kirby, J., Plater, A., and Brinson, M., 2009. *Temperate Coastal Wetlands: Morphology, Sediment Processes, and Plant Communities.* In: Perillo, G., 2009. *Coastal Wetlands an Integrated Ecosystem Approach 1st ed.* Amsterdam: Elsevier.

Pugh, D, 2004. *Changing sea levels : effects of tides, weather and climate.* Cambridge, UK: Cambridge University Press.

Restemeyer, B., Woltjer, J., and van den Brink, M., 2015. A strategy-based framework for assessing the flood resilience of cities – A Hamburg case study. *Planning Theory & Practice.* [online] 16 (1), 45–62.

Schwartz, J., 2018. UNDERWATER.(rising sea levels force coastal communities to retreat inland) (Case study). *Scientific American.* [online] 319 (2), 44–55.

Snodgrass, E., 2011. *El Nino - Walker Cell Explained.* [online video] Youtube. Available at: <https://www.youtube.com/watch?v=f-r82_HRfNw> [Accessed on 28 January 2019].

State of New Jersey Department of Environmental Protection, n.d. *Frequently Asked Questions New Jersey Department of Environmental Protection Superstorm Sandy Blue Acres Buyout Program.* [online] State of New Jersey Department of Environmental Protection. Available at: <https://www.nj.gov/dep/greenacres/pdf/faqs-blueacres.pdf> [Accessed on 22 October 2018].

Woodbridge Township, 2016. *Woodbridge Township Open Space and Flood Plain Restoration Plan Woodbridge Township, Middlesex County New Jersey.* [online] Woodbridge Township, New Jersey: Woodbridge Township. Available at: <http://www.twp.woodbridge.nj.us/DocumentCenter/View/7942/Woodbridge-Township-Open-Space-and-Floodplain-Restoration-Plan> [Accessed on 15 October 2018].

Woodbridge Township, 2018. *Land Use and Development Ordinance.* [online] Available at: <http://clerkshq.com/Woodbridge-nj> [Accessed on 15 October 2018].

U.S. Department of Commerce, 2013. *Economic Impact of Hurricane Sandy Potential Economic Activity Lost and Gained in New Jersey and New York.* [online] Washington D.C.: U.S. Department of Commerce. Available at: <https://www.commerce.gov/sites/commerce.gov/files/migrated/reports/sandyfinal101713.pdf> [Accessed on 25 October 2018].

Vancouver Heritage Foundation, n.d. *Canada Packers Building.* [online] Available at: <https://www.vancouverheritagefoundation.org/location/750-terminal-st-vancouver-bc/> [Accessed on 23 January, 2019].

Virtual Soil Science Learning Resources, n.d. *Why does Vancouver have four soil management groups?* [online] Vancouver, British Columbia: University of British Columbia. Available at: <https://vancouversoils.ca/soil-formation/> [Accessed on 1 September 2018].

Waterfront Toronto, n.d. *West Don Lands.* [online] Available at: <https://www.waterfrontoronto.ca/nbe/portal/waterfront/Home/waterfronthome/precincts/west-don-lands> [Accessed on 25 November 2018].

Wolanski, E., Brinson, M., Cahoon, D., and Perillo, G., 2009. *Coastal Wetlands: A Synthesis.* In: Perillo, G., 2009. *Coastal Wetlands an Integrated Ecosystem Approach 1st ed.* Amsterdam: Elsevier.