MEADOWS IN THE SKY
Contemporary Applications for Eco-roofs in the Vancouver Region

by

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ABSTRACT

In Vancouver, British Columbia, Canada, issues once thought isolated to large metropolitan areas such as Los Angeles, Tokyo, and Mexico City—increased storm water runoff, the urban heat island effect, deterioration of air and water quality, and loss of habitat and biodiversity—now threaten a region once described as “lotus-land” (Wynn and Oke, 1992, xi). European research supports the ability of green roofs to mitigate many of these ill effects of urbanization. The investigation undertaken by this thesis explores the role green roofs might play in the Greater Vancouver’s transition to sustainable design and development.

The thesis limits the scope of its investigation to inaccessible, extensive systems, alternately known as eco-roofs, which are relatively lightweight and low-maintenance. The paper reviews the historical and contemporary development of eco-roofs, including past and present motivations for their use and the evolution of construction methods. It then summarizes the potential impacts—aesthetic improvements, increased biodiversity, protection of the roof membrane, meso and microclimate mitigation, improved building insulation, and stormwater management—currently attributed to green roof implementation. The remainder of the thesis evaluates which of these potential impacts apply to Vancouver, in light of the city’s physical contextual setting, and the ambient influences of the Greater Regional District.

The reported benefits of green roofs are numerous, and incremental contributions to improving environmental conditions should not be discounted or trivialized, however, in Vancouver and its region, eco-roofs’ greatest impact, and consequently financial feasibility, resides in the mitigation of stormwater volumes. Eco-roofs’ detain rainfall and slow runoff from the roof during and immediately following a storm event. This reduces peak flows, and corresponding CSO and flooding problems, and encourages a more natural hydrology by increasing the chances for stormwater infiltration. Storm runoff, and issues related to it, constitutes a persistent and growing problem in the GVRD. The ability of an eco-roof’s even thin profile to mitigate this pressing issue could result in widespread, and even unforeseen, positive ramifications.
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INTRODUCTION

An international centre with a serene climate and beautiful surroundings, Vancouver, British Columbia affords its residents and visitors the best of both the built and natural environment. Nestled between the coastal mountains and the Pacific Ocean, Vancouver plays a variety of roles at the regional, provincial, national and international levels. In the midst of this setting, people often forget that Vancouver, like other urban centres across North America and the world, increasingly suffers the consequences of humankind's negative impact on the environment. Issues once thought isolated to large metropolitan areas such as Los Angeles, Tokyo, and Mexico City—increased storm water runoff, the urban heat island effect, deterioration of air and water quality, and loss of habitat and biodiversity—now threaten a region once described as “lotus-land” (Wynn and Oke, 1992, xi).

While architecture may not intentionally aim to contribute to this environmental degradation, its role in the transformation of renewable and non-renewable resources into places of utility and beauty has profound ecological effects. Amongst the wide range of environmental issues associated with building design and construction lies an important resource in mitigating human impact on the environment: green space. As land values increase, and project budgets decrease, this area tends to grow smaller, often limited to the minimum required by code. When possible, city planners often attempt to compensate for this loss by creating parks, gardens and nature reserves. Unfortunately, these areas often end up as arbitrarily scattered patches of vegetation in a sea of concrete and asphalt. With the fundamental layout of cities unlikely to change for some years to come, planners and developers face the challenge of finding other means of increasing and enhancing the amount of greenery in urban areas. One promising option for dense urban settings is the greening of buildings (Johnson and Newton 1996, 47).
THE FOLK TRADITION

Applying vegetation to the exterior of structures is by no means a recent phenomenon. Vegetated roofs have been utilised throughout the world for millennia. The first known historical references to manmade gardens above grade describe the ziggarts or “temple towers” of ancient Mesopotamia, built around 2000 B.C. (figure 1.1).

Evidence suggests that the three upper terraces of these pyramid-shaped artificial mountains were planted with trees.

Perhaps the most famous roof gardens, the fabled terraced hanging gardens of Assyria and Babylon, were built between the eighth and six centuries B.C. (figure 1.2) (Osmundson 1979, 498). The Hanging Gardens of Babylon, one of the Seven Wonders of the World, were purportedly built by King Nebuchadrezzar II “to console his wife, Amytis, who missed the greenery of her homeland, Media” (Osmundson 1999, 112).
Turf roofs, alternately called sod roofs, appeared across Scandinavia and North America early in human settlement history, as both indigenous people and immigrants placed layers of turf on their roofs to improve insulation and provide additional weatherproofing. As the lumber trade developed, the construction industry grew, and transportation improved, these inexpensive, yet labour intensive roofs were slowly abandoned for materials such as wood (and later asphalt) shingles and slate or clay tiles, that were easier to install and maintain while providing better protection from the elements.

CONTEMPORARY SOCIETY'S RENEWED INTEREST

Recently, society has begun to look to this past for the answers to modern day ills. Whether from a nostalgia for the way things once were (or imagined to have been), or a constructive desire to learn from a time that espoused a green approach (even if it was by necessity), the need to connect to the past has become widespread (Farmer 1996, 14). In *Earth to Spirit: In Search of Natural Architecture*, David Pearson describes the poetic sentiments of many when he writes: “Our ancestors were more sensitive to their environment. They developed a particular sense of place and time, and knew the vital importance of honouring the primeval forces. Everywhere, indigenous building strove to express a harmony between people, land, and cosmos—to make forms that linked earth to spirit” (12). Elements of the natural environment, such as climate and locally available materials, played a vital role in the selection of site, form and fabric for the structures of many past indigenous cultures and historical eras. Time tested knowledge of techniques and materials, passed from one generation to the next and varying from region to region constitute what is known as the folk or vernacular tradition.
The potential role of these traditions in contemporary construction has attracted the attention of governments, academics and the general population alike. Many late twentieth-century architects resonated this interest in their buildings, some integrating traditional forms into the language of their architecture, others 'dropping out' and joining the instinctive do-it-yourself trend of making handmade houses (Farmer 1996, 14). World governments, faced with growing environmental ills, have recognized the potential tools that lie in traditional building techniques. The most recent international impetus for discussing environmental action was the 1992 Rio Earth Summit. In its proceedings, *Agenda 21*, under the section on the management of human settlements, conference members specifically recommended: (1) the use of local materials and "indigenous building sources," and (2) the use of incentives to promote the continuation of traditional techniques, with regional resources and self-help strategies (Steele 1997, 13).

Pre-industrial people established principles of design which contemporary society ignores at great costs (Fitch 1990, 266). While it may be appropriate to review vernacular architecture and its principles, it would be a mistake to romanticize or literally imitate the forms. People cannot be expected to forego the standards of living made possible by technology and return to a pre-industrial lifestyle. In many respects this would be neither possible nor desirable. The limited resources and construction technology of pre-industrial architecture at times resulted in the utilization of resource depleting strategies.

The picturesque turf roofs of medieval Scandinavia may appeal to contemporary society's nostalgic fantasies or appear to convey a sense of environmental responsibility, however, in this era of almost excessive choices, professionals must make a conscious effort to evaluate the applicability of green roofs in their respective contemporary contexts. In a world with
dwindling resources and close to six billion people, many traditional techniques are simply inappropriate.

DEFINING GREEN ROOFS

The term green roof, as well as various others—roof garden, living roof, turf roof, sod roof, and eco-roof—have been used loosely over the years to describe a number of different architectural and landscape treatments for roofs. The Romans made a clear distinction between landscape roofs and the more popularly known “hanging gardens.” The term “solaria” denoted the former, which included pergolas covered in trailing vines, while “hanging gardens” or “horti pensiles,” referred to tree plantations on man-made substructures. The latter term originated in contemporary Roman usage around the birth of Christ, although the phenomenon thus designated is thought to be far older (Pieper 1987, 98).

In contemporary discussions, green roofs are defined as ‘contained’ green spaces on top of human-made structures (Peck, et al. 1999, 13). These spaces can exist below, at, or above grade, but in all cases the vegetation is not planted in the ‘ground.’ Green roof systems are generally divided into two groups: extensive and intensive. Extensive green roofs involve thin substrates of typically 8-20 cm (3-8 in) and vegetation that typically requires minimal maintenance. Their light weight, ranging from 115-300 kg/m² (23-60 psf [pounds per square foot]) fully saturated with water, sometimes allows for installation onto buildings without modifying the structure. Extensive systems can be placed on low-slope roofs and pitched roofs with up to a 40 percent slope (Boivin and Challies 1998). Eco-roofs, living roofs, and the more commonly known, sod or grass roofs fall under this category.
*Intensive* green roofs, on the other hand, refer to the more classic roof top gardens. The soil depth typically ranges from 25-100 cm (10-40 in) and can support the growth of shrubs and trees. The building beneath must be able to support dead loads of 125-2000 kg/m² (25-400 psf), and the roof is typically only sloped to drain. Maintenance requirements for the garden are high, similar to green spaces on the ground (Boivin and Challies, 1998).

Both extensive and intensive green roofs can be further classified as being either ‘accessible’ or ‘inaccessible.’ An accessible green roof essentially provides an outdoor room. Vegetation appears as it would at grade, or in containers and raised beds, separated by walking surfaces. Inaccessible roofs, on the other hand, are only accessible for periodic maintenance. Many extensive systems fall under this latter category, which is often associated with a building’s structural constraints.

**THESIS OBJECTIVE**

The greening of rooftops cannot compensate for the loss of open space and its subsequent ramifications; however, the planting of these hardscapes may ultimately play an important part in the larger scheme of environmentally responsible design. While green roofs appear popular in parts of Europe as a means of addressing environmental concerns, careful consideration should be given to their applicability to Vancouver and its region. Despite similar climatic and economic conditions, the success or failure of these roofing systems relies on the unique regional characteristics—both physical and cultural—as well as the specific needs of Vancouver.

In an effort to address the broadest potential application of green roofs and their respective impacts, the thesis intends to limit the scope of its investigation to inaccessible, extensive systems, henceforth referred to as eco-roofs. These low weight, low maintenance, and consequently, lower cost systems dramatically reduce, and sometimes eliminate, the structural
and garden maintenance concerns (and often barriers) typically associated with green roof implementation. As such, eco-roofs represent the most readily implemented form of green roof construction.

The thesis intends to first review the historical and contemporary development of eco-roofs, including past and present motivations for their use and the evolution of construction methods. The paper will then proceed to summarize the potential impacts—aesthetic improvements, increased biodiversity, protection of the roof membrane, meso and microclimate mitigation, improved building insulation, and stormwater management—currently attributed to green roof implementation. Looking at Vancouver’s physical contextual setting, and the ambient influences of the Greater Regional District, the remainder of the thesis seeks to determine which of the potential impacts, if any, may apply to Vancouver and to what degree. The statistical analysis needed to evaluate, in precise quantitative terms, how different percentages of eco-roof applications might affect the region lies beyond the scope of this work. The purpose of this thesis resides in critically exploring, on a conceptual level, what place eco-roofs might have in Vancouver’s future.
HISTORICAL PERSPECTIVE

The history of extensive green roofs, more commonly referred to as turf or sod roofs, spans over five millennia and at least two continents. Sod has been used extensively in the Northern Hemisphere, especially in regions with cold climates and/or limited resources. As a building material, sod historically consisted of the surface strata of soil and the live roots and rhizomes that occupy it, and give it strength. While both sod and turf are similarly defined as containing a dense growth of grasses, the composition of this surface layer varied from region to region. On the Great Plains of North America, building sod derived from "mixed and short-grass prairies that began to develop in Miocene times" (figure 2.1) (Oliver 1997, 215).

Details about many early forms of sod construction remain either sketchy or non-existent. In Scandinavia squares of pasture were laid over birch bark to form the roof. As seasons passed, the roots intertwined between sods, creating a contiguous whole. In North America, reminiscences and photographs depicting the latter part of the nineteenth century detail the use of sod blocks. Strips of sod, 7-10 cm (3-4 in) thick and typically 30-45 cm (12-18 in) wide, were sliced parallel with the soil surface using special ploughs, or
by hand, with an axe and/or shovel (figure 2.2). The ploughs would turn the sod onto its top in an unbroken slab. The sod would then be cut into varying lengths, 1 m (3 ft) being the longest. These blocks were “laid in masonry fashion, grass side down, to form walls and then thinner blocks used to cover the wood framed roof” (Oliver 1997, 1877). Sod roofs were widespread both temporally and spatially, and proved an invaluable building material in areas with limited sources of wood and/or cold winters.

FROM NEOLITHIC PEOPLE TO THE IRON AGE

Archaeologists believe that a number of the earliest dwellings in both Europe and North America were constructed of limited amounts of wood, stone, and a good amount of sod. The Orkney Isles of Scotland posses some of the oldest houses in Europe. The southernmost of the two archipelagos that form the northern isles of Scotland, the Orkneys are virtually treeless and the geological base, mainly sandstone. The now roofless, but otherwise intact masonry walls of ancient houses, dated from 3600 to 2500 B.C., have been excavated at a number of sites (figure 2.3).

Later dwellings suggest that the roofs of these structures were thatched with straw or turf, held in place with simmons (straw or heather rope) and weighted with flagstone at the eves (Oliver 1997, 1393).
Tobias Faber writes that in Denmark during the Iron Age (500 B.C.-800 A.D.) roofs consisted of rafters, supported on a row of posts up the centre or by two parallel rows of posts along the walls, covered with a framework of branches or light thatch, and a layer of turf or peat.

THE VIKINGS AND THE NORTHERN ATLANTIC

The Norsemen of Scandinavia cut turf in several shapes and sizes from pastures and sedge marshes with special tools and used it extensively in the construction of their settlements as they began to expand into Europe and explore the Northern Atlantic from the end of the Iron Age (700 A.D.) and into the Viking Age (800-1000 A.D.) (figure 2.4) (Donnelly 1992, 20).

On the Orkney Isles, the Vikings used flagstone and/or simmons to form a sloped roofing deck, which was then "thatched with straw or turf, held in place with yet more closely spaced simmons weighted with flagstone at the eaves" (Oliver 1997, 1394). Similar techniques were used on the Shetlands Isles around the seventh century and the Faeroe Islands in the late ninth century. Even as wood construction began to replace the old traditional house, most of the
stave-built outbuildings on the Faeroes, that form part of the house or farm, had roofs covered with turf. Timber-lined buildings faced externally with turf could be found on the Shetlands as late as the twentieth century. In his 1966 book, *The Historic Architecture of Scotland*, John Dunbar wrote that the practice of “pegging squared turf roots upwards to the rafters as a sole covering has been recorded in Shetland within the past generation or so” (232).

From the time the Vikings arrived in Iceland in the late-ninth century, until the late-nineteenth century, the primary construction materials in this bare land were stone, wood, and turf. Icelandic turf buildings were “wooden buildings surrounded by protective walls and roofs of turf and stone” (Oliver 1997, 1389-90). The timber used in construction came in the way of driftwood and later imported timber. As late as the early 1900’s more than half the population of Iceland lived in turf farmhouses. While the majority of these structures were replaced soon thereafter with wood, and then concrete, in some places, people continued to live in them even after World War II (Oliver 1997, 1389).

The most common roof construction used in Iceland was the *sperruthak* or spar-construction (A-frame couples). “The roof, protected with turf on the outside, is covered in two different ways: *helluthak* which has flat stone pieces laid on the rafters on which are placed earth and then turf with the grass facing out; or *tróðthak* which has brushwood instead of flat stones laid on the rafters with first turf, then earth and finally turf with the grass facing outwards, placed on top” (Oliver 1997, 1390).
Later periods saw primarily two kinds of turf buildings. One involved a structure built entirely of turf blocks (slabs), laid to form domed or barrel-vaulted roofs (figure 2.5). The other was a wooden dwelling, where the front was panelled with wood, and the roof and walls were made of turf (figure 2.6) (Donnelly 1992, 235). The latter is still associated with Iceland, and is a popular subject for picturesque postcards.

The Vikings went on to use similar roof and wall construction in their short-lived settlements on the icy landscape of Greenland in the late tenth century and on the North Atlantic coast of Canada in the twelfth century (figure 2.7) (Kalman 1994, 12).

**SCANDINAVIA**

Turf roofs were used extensively in the medieval period on farm buildings throughout Scandinavia. While wood was plentiful and sod was heavy, turf roofs possessed good insulation qualities compared to other roofing materials in use at the time. These roofs had to be renewed
regularly when the turf degenerated or when small branches sprouted. Lifespan estimates, though, ranged from 20 years to 40 or more.

The roofs generally consisted of a layer of robust boarding, one or more layer(s) of birchbark, with all the pieces generously overlapping, a network of birch twigs, a thin layer of gravel, and then finally two courses of turf, the first upside down (figure 2.8). While it was possible to omit the twigs and gravel, the roof did not perform as well or last as long without them. A later variation of this construction used a corrugated waterproof layer of tough plastic in lieu of the birchbark.

The eaves at the bottom of the roof were finished by a solid board held in place with hooks that extended some distance up the roof under the birchbark. The birchbark/waterproof layer had to “continue under the eaves board and form a water drip nosing clear of the roof boarding.” A substantial piece of timber, a form of bargeboard, “held in place by long wooden pins bored through the board and dug well into the turf,” was often used on the gabled eaves (Oliver 1997, 360). The roof had to have a pitch that allowed it to drain well, where the turf could be held in place, and where snow could settle in the winter; this was often around 27 degrees (Oliver 1997, 359). There is little written on how well these roofs kept out the elements.

The above roofs were intended to be permanent, and their multi-layered construction, sometimes involving up to seven layers of birchbark, does suggest they were effective barriers against the rain and the cold.
In the province of Telemark, in southern Norway, where the main building material was timber, walls would be constructed with logs, and the roof topped with turf. During the eighteenth and up to the mid-nineteenth century, on the eastern coast of Sweden and on Gotland Island, the corner-timbered dwellings had pitched roofs covered with turf, straw, reed, or split logs. It wasn’t until the late-nineteenth century that these were replaced with increasingly popular tiles (Oliver 1997, 1395). The national open-air folk museums of Norway, Denmark and Sweden all include a number of turf-roofed structures dated between the seventeenth and nineteenth century (figure 2.9) (Donnelly 1992, 220-225).

THE ARCTIC

Indigenous Peoples—Winter House

Archaeological analysis suggests that the history of Arctic architecture stretches back some 25,000 years (Easton and Nobokov 1989, 191). Clear evidence of early dwellings begins with the Dorset Culture around 800 B.C. The Thule, the direct ancestors of today’s Inuit, began to spread their remarkably uniform culture from the
Pacific Coast in the eleventh century, reaching Greenland in the thirteenth century. While snow-blocked igloos come to mind as the typical winter Inuit dwellings, this form was probably limited to the Central Arctic. Far more common across the thousands of miles of tundra were winter structures framed with whatever materials could be found—rocks, driftwood, animal skeletons—and insulated with layers of dirt, skins, packed snow or sod (figure 2.10) (Easton and Nabokov 189-190).

From the Inuit on St. Lawrence Island, with their semi-subterranean ningloos, to the extraordinarily wide Eastern Greenland winter houses, turf played an important role in the construction and insulation of Inuit winter dwellings. While variations in building material resources and local customs dictated the various shapes and sizes of dwellings, the construction involved several basics: excavating the site to some degree, creating a frame using the materials available, and then covering the frame with sod (figure 2.11). The North Eastern Greenland Polar Inuit constructed their roofs of corbelled sandstone slabs supported by interior driftwood or bone uprights, over which sod, earth, and then more sod was laid (Easton and Nobokov 1989, 192).
The inhabitants of the Aleutian Islands built some of the largest native homes of the Arctic. Called *barabaras*, these buildings sometimes measured up to 60 m (180 ft) long. The thatched roof, sealed over with grassy turf, made these communal buildings blend into the terrain. In fact, after the introduction of cattle, it was not unusual for a grazing cow to tumble through the sod into the group's living space (Easton and Nobokov 1989, 205).

In parts of the western Arctic and Alaska, where timber was more readily available, sod-covered houses were wood-framed (figure 2.12). The greatest variety of wood-framed winter houses existed along the North Alaskan coast. In the southernmost portion of the Alaskan territory, the influence of the First Nation architecture of the Northwest Coast, resulted in Inuit groups using sod-covered gabled structures built on a rectangular plan, similar to the plank buildings of the Tlingit (Easton and Nabokov 1989, 193).

**Settlers**

Trappers, adventurers, miners, and settlers of the North also took advantage of the insulating properties of sod. In 1897, the gold rush to the Klondike increased the number of Caucasians in the region by five times in just one decade. These new arrivals tended to construct cabins of a temporary nature, built of round logs laid horizontally, often not even peeled of their bark. "The gable roof was constructed of thin poles laid perpendicularly to the ridge-pole, then
covered with 30 cm of sod or moss for insulation” (Oliver 1997, 1794). Over time the sod might have been covered with flattened fuel cans, forming metal shingles.

Following European contact, a number of native peoples in Alaska began to construct sod-covered log houses, in lieu of their traditional dwellings. The last manifestation of the Aleutian barabara, mentioned earlier, was a gable-roofed, double-walled plank house with an external skin of sod bricks (Easton and Nobokov 1989, 205).

THE GREAT PLAINS

The Great Plains cover an expansive area that extends from southern Saskatchewan and Manitoba in Canada to Mexico (figure 2.13). The flat terrain of the Plains was for the most part a treeless landscape with an immense sky. Early explorers called the Prairie Plains the “Great American Desert,” as much of the vast region they encountered was largely waterless, treeless, and featureless (Oliver 1997, 1874). Although the home to primarily nomadic hunters, a small number of early farming cultures, semi nomadic people, were known for their circular earthlodge villages. The settlements of the Mandan, in what is the present day Dakotas, became renowned centres of trade by the 1780’s (Easton and Nobokov 1989, 126).
Indigenous Peoples—Earthlodge

Earthlodges first appeared on the North American Plains around 700 A.D. Archaeological work suggests that the earliest earthlodges were rectangular and their successors circular. Tribes constructed their earthlodges in more or less the same fashion. Building entailed constructing a wooden frame to hold the earthen walls and to support the heavy roof. The roof included a layer of smaller sticks overlaid with brush or grass, followed by a thick layer of sod or loose earth (figure 2.14). A typical earthlodge measured up to 20 m (60 ft) across and 30 m (90 ft) wide. Although limited resources inspired these sod-covered designs, a number of indigenous people continued to use them even after wood became readily available. It wasn’t until the late nineteenth century when the government forced them to live in log cabins or wooden frame houses, did they finally abandon this traditional dwelling (Easton and Nobokov 1989, 123-143).

North American Settlers—Dugouts and ‘Soddies’

To prospective settlers the seemingly limitless sea of grass exerted an irresistible attraction. Many U.S. Civil War survivors saw the opportunity to raise beef for the growing demands of the Midwest cities, and the government began to encourage the immigration of the ‘huddled masses’ of Europe ‘yearning to breathe free’. Hailing largely from the Germanic and Nordic countries, the Baltic, and central and eastern Europe, many were familiar with extremes
in temperature and bitter winds, yet few could have anticipated countryside so bare and bereft of cover, protection, and more importantly building materials.

With treeless grassland stretching for miles, lumber had to be transported by wagon at an exorbitant cost. Settlers with slim financial resources depended on improvisation, ingenuity, and the materials at hand, to build their underground or semi-underground dugouts and later sod houses, barns and schools. Popular in the southern plains, dugouts involved digging a room into the ground or a hillside, and then covering it with a roof of planks that might rest on a low wall of fieldstone or timber wall plate. Upon this would be laid brush, earth and sod (figure 2.15) (Oliver 1997, 1875-77).

Father north in Oklahoma, Kansas, Nebraska, Wyoming and Montana, settlers built early ‘soddies’ into a hill or partially underground, with sod walls rising above the excavation. ‘Soddies’ were considered temporary dwellings that would provide basic shelter until there was time and/or money to build a more permanent frame house with board and batten. A simple roof consisted of forked posts to hold up the roof-ridge and freighted in poles to form the rafters. Builders finished the roof with a layer of brush, a layer of prairie grass, and finally with sod ‘bricks’, either grass side up, or grass side down. The latter version was more desirable, as less dirt would drop from the ceiling.

Later ‘soddies’ were freestanding structures built with sod blocks (figure 2.16). If settlers could afford the lumber they would construct a frame roof, cover it with sheeting and tarpaper and finish with blocks of sod (Oliver 1997, 1877). The sod acted to both weatherproof
the roof and ballast the tarpaper. The roof planks were either, rabbeted and lapped, or butted together with strips of lath at the joints in order to discourage leaking (Gulliford 1986, 56). Unfortunately, as the sod covering dried and the earth cracked from the sun, the planks warped and leaked at the joints. It was a common saying that with a sod roof, if it rained one day outside it rained two days inside (Shepherd 1977, 45). The weight of saturated soil (15 cm [6 in] of sod weighs approximately 244 kg/m² [50 psf]) coupled with the usually inadequate frames, on occasion, also caused the roof to buckle and collapse after a soaking spring rain.

Over one million sod buildings were in use on the plains of Canada and the U.S. from 1903 to 1913 (Shepherd 1977, 45). Immigrants, from a number of different ethnic groups across Alberta, Saskatchewan, and Manitoba used sod in the construction of their buildings. Mennonite settlers in Alberta and Manitoba built semlins, sod houses that housed both family and livestock under one roof, in the late 1800’s (Roe 1970, 1; Kalman 1994, 349). In 1899, Russian Doukhobor immigrants, given three large areas to settle in Saskatchewan, built substantial log houses where good timber was available, and soddies where it was scarce. In both cases, though, the roofs were pitched low and generally covered with prairie sod.
NORTHWEST PLATEAU REGION

While the architectural history of the Northwest region remains unclear, most tribal traditions suggest that the oldest house form was the pit house (figure 2.17). The shape and construction of pit houses varied throughout the Plateau region. While similar in construction to the earthlodges of the plains, pit houses were considerably smaller and sunken three to four feet into the ground, before being covered with the earth and then sometimes sod (figure 2.18). Families moved into these underground houses in the late fall, and stayed until the spring.

Settlers and trappers also used pit houses in the interior regions of British Columbia, but considered them temporary dwellings. After clearing their site, pioneers would erect a more permanent notched log house. The roofs of these permanent buildings were sometimes covered with a thick layer of turf for insulation (Dangelmaier 1989, 16). The small, short-lived community of Wallahachin, located on a ‘bench’ above the Thompson River, had several shallow-pitched roofs covered with bark and turf (Oliver 1997, 1813).
THE DECLINE OF SOD

From Neolithic times to the mid-nineteenth century, sod represented an important material for a number of people in resource scare regions, and as a form of insulation in many northern latitudes. Growing means of transportation and changing social standards in the mid-nineteenth and early twentieth century eventually pushed sod into the history books. In North America, the spread of the railroad dramatically increased options for builders across the Plains. Small sawmills sprang up throughout the 1850's and 1860's as more and more people sought lumber to build their houses. Sawed pine boards and machine-made wire nails, cut to standard sizes, and ready-made products such as doors, windows and trim became widely available. People could order entire prefabricated buildings of all types from catalogues. The increased availability of building materials coupled with publications about building encouraged people to adopt new methods of construction (Kansas State Historical Society 1998).

Settlers across North America welcomed materials that allowed them to build homes of more permanence and in the tradition of their respective ethnic groups. For many indigenous people, though, this transition came rather abruptly, as the government began forcing them to give up their traditional dwellings and life style. The use of sod and turf roofs did continue sporadically in a number of rural areas, particularly in Europe, for many years though. It also became an attractive option to many North American “back-to-the-land” enthusiasts in the 1960’s. However, it was not until the 1980’s that green roofs began their return as a viable roofing option.
CONTEMPORARY USAGE

The 1980’s saw a renewed interest in green roofing in Europe. With the motivating factors of the past long remedied—limited building materials and/or construction technology—Europe faced new challenges: the rapid decline of green space in the urban landscape and the degrading quality of the environment. Several European countries, including Germany, Austria, and Switzerland, looked to green roofs to: improve air quality; help mitigate the urban heat island effect; reduce stormwater runoff; improve building insulation; and increase green space and biodiversity in urban centres.\(^1\) Progress in horticultural engineering, including improvements in drought-resistant plants, and advances in waterproofing systems aided the gradual development of a viable green roof industry (Boivin 1997, 45).

EUROPE

Germany has been one of the most aggressive pursuers in this trend. Today many German cities possess by-laws that ensure that industrial buildings incorporate a green roof.

Stuttgart, a city of a half million people, specifically subsidizes green roof installation on industrial buildings (figure 3.1). The city will pay up to 50 percent of the cost required to construct a green roof and provides a higher subsidy per square meter in urban renewal districts.

\(^1\) The ‘urban heat island effect’ denotes a mesoclimate condition where the temperatures in an urban area are higher than the surrounding countryside.
Stuttgart has thus far spent over three million Deutsche Marks (just over $2 million Canadian) on the subsidy project. In 1998, the city of Mannheim adopted a ‘greenification policy’ for its urban core. The policy requires that green roofs be installed on new or altered development. Any roof with up to a 10-degree slope requires conversion, and in order to compensate developers and building owners for the additional expense, higher densities and building heights are allowed (Beckman et al. 1997).

Germany’s Federal Environmental Law requires town planning to contribute to the protection of the environment and that compensation measures be taken when nature is disturbed by development. Planning polices that require or encourage green roofs have created results. In 1997, out of the estimated 80 million square meters of flat roofs in Germany, approximately 10 percent of them were greened (Beckman, et al. 1997). This translates into over 55 million square metres of green roof infrastructure developed between 1989 and 1997. Eighty percent of these green roofs are extensive systems.

According to reports published by the ZVG (Germany’s central horticultural society), by GALK (the park administrators in the German League of Cities), and the FLL (the research society for landscape construction and development), 43 percent of German cities offer financial incentives for roof greening (Osmundson 1999, 31). Twenty-nine of the 193 larger cities in Germany give direct financial support to roof gardening, and 13 give indirect support by allowing deduction in the calculation of sewage disposal fees. Forty-one cities accept roof gardening as a measure to mitigate the ecological impact of building construction and 27 will only issue permits for flat roofs if greening of the roof is stipulated (Osmundson 1999, 32).

Germany has established an ecological compensation program to regulate building construction. Every development results in the loss of living space for flora and fauna and the
loss of ground water to the sewer system. In order to offset this loss, building permits are connected to what is called a “biotope evaluation.” Potential developments are assigned biotope values in relation to the values of the original area. In order to obtain a building permit, the developer must compensate for the difference in the values. For example, the loss of a meadow might be compensated for by planting greenery on the roof, collecting rainwater, or planting creepers along the walls (Sonntag 1999/2000, 12). While it has taken some time for the building community to accept green roofs, builders now generally agree that green roofs add to a building’s performance, durability, aesthetics, and value (Beckman, et al. 1997).

Green roofs are now commonplace in a number of countries including France, Switzerland, Scotland, Monaco, Belgium, the Netherlands, and Italy, as a result of aggressive government legislation and generous financial support. In the Netherlands, a “path-breaker” in adopting environmental legislation, green roofs adorn such projects as the Schipol International Airport and the environmentally progressive community of Ecolonia (figure 3.2) (Simons 1994, A3). In Oostmalle Belgium, the Ecover manufacturing plant, which has been called “the world’s first ecological factory,” consists of more than two acres of native grasses and wildflowers (Thompson 1988, 48).

The Swiss have taken quite an aggressive approach to green roof implementation in that they require all new buildings to relocate the green space covered by the building’s footprint at
grade to the rooftop, and existing buildings, regardless of age or roof slope, to green 20 percent of their rooftopscape (Kuhn 1995). The city of Linz, Austria has also implemented a vigorous roof greening program. This city requires developers to compensate for any green space lost in development by covering an equivalent amount of space with greenery. “Since the 1980’s, Linz has subsidized the cost of green roofing by funding up to 35% of the total cost of a green roof” (Beckman et al, 1997). The estimated 35 million shillings (approximately $3.5 million Canadian) of subsidies has helped grace the city with more than 300 green roofs. This type of government legislation and financial support has allowed green roof technology to become well established in the research, industrial, and development sectors of Europe. In Germany alone, the green roofing industry, a multi-million dollar market for green roof products and services, has grown 15-20 percent annually since 1982 (Peck, et al. 1999). The France-based roofing membrane manufacturer Soprema has installed more than 92,000 m² (990,280 ft²) of green roofing, mostly extensive, throughout France since 1989.

ASIA AND OCEANIA

Green roof legislation is not limited to Europe. In Asia, one of the largest cities in the world, Tokyo, Japan recently recognized the potential role of green roofs for mitigating its urban heat island and stormwater runoff. As of April 1, 2000, new public and private commercial developments with roof areas over 250 m² (2,691 ft²) and 1,000 m² (10,764 ft²), respectively, are expected to green a minimum of 20 percent of any flat roof area. While the new legislation acts more like a design guideline, in that compliance is not required, developer feedback has been quite positive. According to Hideo Hara, a supervisor in the City of Tokyo’s Department of the Environment, the above legislation represents an addition to an older law that asked that 20 percent of the building site be greened (Hara 2000).
South of the Equator, the City of Port Phillip in Victoria, Australia has been researching the practicalities of vegetated rooftops with funding assistance provided by a State government 'Pride of Place' urban design grant. Over 40 students from four universities in Australia have been involved since 1998 in research intended to give local residents, designers, council officers, and developers a better idea of the social, environmental, and economic costs and benefits of green roofs specifically related to Australia (Port Phillip EcoCentre).

NORTH AMERICA

While 20 years ago, finding people in Canada and the U.S. to install a green roof would have been nearly impossible, today a growing number of European-based (Soprema) as well as several U.S. waterproofing companies now offer such services. Green roofs, particularly extensive systems, however are still poorly understood, little researched, and the market remains immature and marginal in North America (Peck, et al. 1999). Until recently, the argument for planting roofs in Canada and the U.S. had been largely focused on aesthetics. Now, a growing number of cities, including Portland (Oregon), Chicago and Toronto, and several organizations have begun researching and promoting the broader environmental implications of green roof usage.

United States

In Portland, Oregon, city planners are particularly interested in the stormwater mitigation properties of green roofs. Faced with the high cost (more than US$750 million [approximately $1.1 billion Canadian]) of solving its politically charged Combined Sewer Overflow (CSO) problem, the City's Bureau of Environmental Services (BES) is interested in using eco-roofs to
retain stormwater on developments, particularly those near the Columbia Slough.\(^2\) Portland’s Central City Plan has a roof garden bonus, which allows new developments an extra square foot of building for each square foot of roof garden. To qualify the developer must cover at least half of the roof with a garden, 30 percent of which must be vegetation. This bonus, however, has not been used in the seven years since its inception, as developers have opted for other less expensive ways to get bonuses (Beckman et al. 1997).

In Chicago, Illinois, green roofs will soon play a part in the city’s plan for addressing its urban heat island. The city’s initial interest in green roofs began after the mayor, Richard Daley, returned from a trip to Europe. Impressed by what he saw there, Mayor Daley came back determined to incorporate green roofs into Chicago’s urban fabric (Daley 2000). While Chicago’s building codes and zoning neither prohibit nor discourage the use of green roofs, people’s perception of them, according to Brenden Daley, a staff assistant in Field Operations with the City of Chicago’s Department of Environment, is an obstacle. Daley feels that, in general, people just don’t see the point of them (Daley 2000).

The city’s environmental department intends to plant the roofs of several city buildings in four pilot wards of the city as part of a U.S. Environmental Protection Agency (EPA) and Department of Energy program studying ways to help cool cities and reduce smog. This rooftop gardening initiative is part of Chicago’s larger Heat Island Reduction Initiative. City Hall will be one of the first buildings to receive a rooftop makeover with an inaccessible intensive system. The $1 million green roof demonstration and laboratory will cover more than 50 percent of the total roof area, and showcase three different soil depths and a variety of plants, including trees

\(^2\) CSO problems exist in a number of older North American cities, including Vancouver, that still rely on combined sewer and stormwater pipes. During heavy rainfall the system becomes overburdened and overflows, spilling untreated sewage into nearby water bodies.
(Peck & Associates 2000, 4). The majority of the other intended recipients will likely be covered with extensive systems (Daley 2000). Chicago is one of five cities participating in the EPA program and the only one promoting rooftop greening.

Canada

In Canada, Toronto, Ontario is also particularly interested in the heat island mitigation effects of green roofs. In July of 1999, Toronto Public Health proposed a Hot Weather Response Plan to lessen the impact of summer heat on at-risk populations. In the plan, they identified the need to look at the potential role of green roofs. Toronto’s Environmental Task Force’s Sustainable Energy Plan notes that Toronto has “huge unexplored potential to achieve reduction in cooling load, improved air quality, reduced noise and improve the City’s ambience through planting of backyard and street trees, rooftop gardens and parking lot trees in neighbourhoods and public spaces” (Peck & Associates 1999, Winter). In April of 2000, the City of Toronto’s Environmental Task Force (ETF) presented its proposed Environmental Plan, Clean, Green and Healthy: A Plan for an Environmentally Sustainable Toronto, to City Council for approval. Among the 63 recommendations is one that proposes a Sustainability Roundtable before the end of 2000 on a strategy to encourage green roofs and rooftop gardens. Specific green roof recommendations in the Plan include: (1) addressing the potential for retrofitting green roofs and rooftop gardens on City-owned buildings; (2) looking at how green roofs and rooftop gardens can be implemented in new developments; and (3) investigating the environmental benefits that can be derived from green roofs and rooftop gardens (Peck & Associates 2000, 1). The EFT has recommended that the City allocate $30,000 for a green roof strategy team and $250,000 for a City Hall demonstration project (Peck & Associates 2000, 2).
Interested in quantifying the benefits of green roofs, several organizations in Toronto and Ottawa plan to conduct independent and comparative research studies using buildings in their cities. In Toronto, Green Roofs for Healthy Cities, a business coalition interested in fostering the development of a market for green roofing, hopes to install and monitor the membrane, and energy and stormwater benefits of the green roofs on two city-owned buildings. One of the demonstration sites will be located on the 464-m² (4,994 ft²) roof of the Eastview Community Centre, the other on a 557-m² (5,995 ft²) portion of the podium roof at City Hall. The first project will be an inaccessible, extensive system, the latter, an accessible, extensive system. In partnership with the National Research Council and Environment Canada the coalition has applied for over $300,000 in funding from the Technology for Early Action Measures (TEAM) program to conduct the research. The group expects the City Hall project to help potential green roof clients and industry representatives understand green roof technology, as a variety of applications at different soil depths and plant communities have been planned. The University of Toronto is also interested in pursuing research on water quality and native plants at the City Hall site (Peck & Associate 2000, 2).

In Ottawa, the National Research Council's Institute for Research in Construction and Environment Canada plans to conduct a two to five year monitoring project to compare differences in water quality, energy usage, and other environmental factors between a conventional and a

3.3 National Research Council's test roof (Liu 2000).
green roof. The project will use a small test house, on the National Research Council campus, that has been structurally upgraded, refitted with a low-slope roof, and split into two thermally isolated sections (figure 3.3). Both sections of the roof will utilize a modified bitumen membrane, and the vegetated portion will be covered with an extensive green system. Using the data gathered by the numerous monitoring devices on the site, including two weather stations, Environment Canada plans to generate and validate a computer model for green roof performance. The project hopes to raise awareness for the potential green roofs hold in helping Canadian cities meet climate challenges.

In Southern Coastal British Columbia, examples of eco-roofs appear, for the most part, scattered and prompted primarily by aesthetics. Owners and developers often cite the desire to have their buildings “blend unobtrusively into the landscape,” as the primary reason for opting for an eco-roof (Backhouse 1988, 68). While urban examples are few and seemingly limited to unintentional carpets of mosses, some rural areas, most notably Hornby Island, boast a number of intentionally sprouted residential projects. In the community of Hornby, about 800 year-round residents, more than 18 houses, the community hall, and the local pub, have sod or planted roofs (Backhouse 1988, 68). Green roofs were introduced to the Island about 40 years ago by one of Canada’s most renowned architects, Arthur Erickson. South of Hornby, in Coombs, on Vancouver Island, stands the Coombs Old Country Market well-known for the family of goats which nimbly graze on its grass roof.

CONCLUSION

No longer motivated by limited building materials and/or construction technology, green roof construction experienced its revival through Europe’s efforts to mitigate environmental degradation in urban areas. Throughout much of Europe, green roof legislation and
implementation have resulted in millions of square metres of low-slope extensive planting and numerous intensive rooftop gardens. Years behind Europe’s densities and environmental challenges, and lacking the more socialistic undercurrent prevalent in many European countries, green roofs in North America have been primarily accessible intensive systems (rooftop gardens) designed to create aesthetically pleasing, recreational spaces for the occupants and tenants of the respective buildings. In Vancouver, examples of this include Robson Square, and numerous condominium and townhouse developments. Only in the past 10 to 15 years have environmental concerns begun motivating green roof implementation, and consequently the increased use of extensive systems. In the chapter to follow, the thesis will discuss the potential benefits and impacts a green roof might have on the building site and the surrounding region.
POTENTIAL IMPACTS AND ISSUES

European research on roofing performance has linked green roofs with a number of potential benefits. These include: sound insulation, improvement of air quality, mitigation of the urban heat island effect, reduction of storm water runoff, improved building insulation, encouragement of urban biodiversity, protection of the roofing membrane, and the creation of psychologically pleasing environments. Research suggests that the green roof usage required by the aggressive environmental laws in both Germany and Switzerland has proved an efficient ecological solution to such problems as air pollution and storm water runoff. It points to such indicators as the reduction of the diameters of the storm sewers in some German municipalities where large surfaces of roofs are greened (Boivin 1997, 46). The performance of a green roof depends on the complex interaction of a number of different variables: climate, roof construction, substrate composition and depth, type of vegetation, to name but a few. This portion of the thesis provides a brief overview of the potential benefits and issues associated with green roofs, and when possible, specifically eco-roofs.

AESTHETICS/PSYCHOLOGICAL

One of the fundamental, albeit subjective, benefits of eco-roofs is their visual appeal. Investigations of aesthetic and affective responses to outdoor visual environments have demonstrated a strong tendency for North Americans and Europeans to prefer natural scenes to urban views lacking natural elements (Ulrich 1984, 420). According to Stephan Kaplan, a professor of environmental psychology at the University of Michigan, the brain seems both aroused and soothed by nature (Landscape Architecture 1995, 60). Psychological studies have demonstrated that the restorative effect of natural scenery diverts a viewer’s awareness away
from themselves and from worrisome thoughts. Swedish research on brain wave activity indicates that “views of natural settings elicit a wakeful and relaxed state characterized by a decreased heart rate and a quicker stress recovery times.” A 1984, Pennsylvania-based study, conducted on the restorative effect of natural views in surgical patients, found that patients with a garden view had shorter post-operative hospital stays, fewer negative evaluation comments from the nurses, and required less pain medication (Ulrich 1984).

The 35.5 cm (14 in) intensive system on the roof of Vancouver’s own Public Library Square was designed to offer a green view to residents of the surrounding office towers, in particular the Federal Building that directly overlooks it (figure 4.1). The grasses—blue and green fescues were planted in a pattern intended to suggest the Fraser River flowing through the Lower Mainland (Thompson 1998, 49).

The ability to blend in with the natural surroundings sometimes represents a deciding factor for local planners, particularly in green belt areas or in the open countryside (Johnson and Newton 1996, 48). Eco-roofs are often used in the United Kingdom to help meld developments with the surrounding countryside, and comply with predominantly rural planning requirements (Beckman, et al 1997). The provision of greenery on the Crédit Suisse Administrative Building in Zurich, Switzerland came in response to stipulations made by planning officials that the roofs should be made to “appear optically green” as they could be seen from Uetliberg mountain, a popular recreational area (Atelier et al. 1986, 11).
BIODIVERSITY

Increasing urban densities have dramatically reduced the habitats of plants and animals in cities around the world (Kölb 1986, 4). As land becomes more intensely developed, plant and animal species unique to an area are displaced and sometimes lost. While green roofs are not substitutes for natural habitats, nor do they justify the destruction of habitats at grade, they can help replace the green space lost to buildings and car parks. Green roofs could potentially create a network of habitat islands. As the number of green roofs increase and the distance between them decreases, the “colonization of the urban environment by those fauna having the necessary dispersal power should increase” (Nature Conservancy Council 1990, 24). Extensive systems offer a unique potential to restore the distinctive flora of a region to city areas, and in time, dependent insect and bird populations. Compared to landscaped areas at grade, typically accessible to people and consequently subject to regular disturbance, the relatively isolated nature of eco-roofs (inaccessible and low-maintenance) provides protected areas for sensitive plant and animal/insect species (Peck et al. 1999, 40).

In some European countries, there has been a recent move to implement more ‘ecological’ landscapes in the urban environment, with an emphasis on planting native rather than exotic species. Native species require less maintenance and can provide habitat for some local bird and insect species. The green roof on the Boyne River Ecology Centre in Shelbourne, Ontario has provided an excellent habitat for indigenous species, so much, in fact, that the grass and wildflowers are more plentiful on the roof than at grade (Peck et al. 1999, Appendix II). The Nature Conservancy Council in Britain has stated that low-maintenance native-plant gardens could make an important contribution to the survival of Britain’s native plants, including rare
species (Nature Conservancy Council 1990, 24). Coincidently, a number of endangered plant species are arid/semi-arid grassland plants, making them good candidates for rooftop conditions.

Native plants also have more insects associated with them, and therefore by encouraging their use, urban fauna may increase in diversity. "Fauna friendly" roof gardens may be established by planting species known to be valuable as food or cover to winged species. The altitude of the garden, its distance from the closest source of wildlife, and the garden itself—plant species, water, food available, and activity levels all affect animal use of green roofs (Nature Conservancy Council 1990, 24). Studies in the United States show that, provided there is a good source of nectar, butterflies will visit gardens located as high as twenty stories (Johnson and Newton 1996, 49). Other species that have been found at high levels include bees on the twenty-third floor, and squirrels and birds on the nineteenth floor (Peck et al. 1999, 40). Birds regularly alight and even nest on the expansive eco-roof of the Ecover Factory in Germany and on the Vancouver Public Library (VPL). According to Darryl Unger, in charge of VPL's building maintenance, a pair of Canada geese has made the Library's roof their annual nesting ground for several years now (Unger 2000). Nelson Gray, a coordinator with the Songbird Challenge in Vancouver who has been promoting songbird friendly, balcony gardens, feels that green roofs could play a role in the effort to address the decline of songbirds in the region (Gray 2000).

**PROTECTION OF ROOF**

Chief among the technical advantages of vegetation on the roof is the protection it gives to the underlying roofing materials. Planted roofs buffer the roof membrane against extremes of climate and ultra-violet radiation, reducing the stress on roofing materials, and extending the life
of the roof (figure 4.2). In the summer, planted areas heat up considerably less than exposed surfaces of asphalt or bitumen. Studies show that an exposed area of a black roof can reach 80°C when an equivalent area beneath grass is only 27°C (Johnson and Newton 1996, 50).

In the winter, green roofs can lessen or even eliminate fracturing of an asphalt roof by frost and ice formation. One study found that while winter temperatures on a gravel-covered roof averaged -12°C, those on the planted roof averaged -5°C (Johnson and Newton 1996, 50). German sources claim that a 10 cm (4 in) thick green roof can reduce the average temperature swing on roofs, from 20-80°C, to 10-30°C. Research by Soprema suggests that heat, not the cold, ultimately compromises a membrane (Boivin 2000). By preventing solar radiation from striking the roof, and therefore minimizing thermal fluctuations, the membrane experiences less stress from expansion and contraction. This reduces the chances of cracking and extends the life of the membrane (Peck et al. 1999, 31).

MESO and MICROCLIMATES

Microclimates are site-specific and directly influenced by a variety of elements on and around the site—land contour, vegetation, water, soil conditions, and buildings—which affect solar access, humidity, runoff patterns, etc. on the property (Peck, et al 1999, 21). Urban areas have the capacity to induce an infinite number of microclimates. Benedicte Dousset has been
comparing surface temperature statistics taken from satellite images of the Los Angeles basin and urban land cover classified using a multispectral SPOT (Satellite pour l'Observation de la Terre) image to correlate the effect of industrial and fully built-up areas, as well as vegetation, on urban microclimates (Steele 1997, 45). Dousset has measured how changes in surface properties (albedo, heat capacity, and moisture content), changes in the airflow due to streets and tall buildings, and heat released by human activities, contribute to the urban heat-island effect.  

Expressing the sentiment of many urban and environmental planners faced with addressing rising concerns about urban and global climate, Dousset believes that the development of sustainable cities requires accurate microclimate databases and a better understanding of the energy exchange at the urban surface in order to:

- Optimize energy-efficient designs at the urban and building scale
- Mitigate the urban heat-island effect by selecting the distribution of vegetation, the layout of city blocks, building size and clustering, and the properties of surface materials.
- Predict the climatic responses of alternative urban planning and designs.
- Coordinate strategies that ensure a healthy environment for the inhabitants and prevent alterations of the regional ecosystem (Steele 1997, 45-46).

Changing a site’s microclimate can have a complex and layered effect on the urban mesoclim ate. Once established, green roofs can have a significant impact on the heat gain and heat loss of the building beneath it, as well as the humidity, air quality, and reflected heat in the surrounding area (Peck et al 1999, 21-22). In several North American cities, such as Chicago and Toronto, green roofs represent an attractive component for their micro and mesoclim ate mitigation plans.

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1. Albedo. The ratio of the intensity of light reflected from an object to that of the light it receives from the sun (Collins English Dictionary 1995, 34)
2. Mesoclim ate. The climate over a small portion of the earth's surface, where it may differ from the general climate of the area, e.g. local and regional climate, urban heat island (Harcourt, Inc.).
Urban Heat Island Effect

The ‘Urban Heat Island Effect’ is a mesoclimate that results from the difference in temperatures between a city and the surrounding countryside. Summertime air temperatures in urban areas can be 3-6°C higher than surrounding non-urban areas. Dark-roofed buildings—along with kilometres of pavement, and hectares of parking lots—absorb the sun’s rays, causing both surface temperature and overall ambient air temperature to rise (U.S. Environmental Protection Agency). Many urban centres also have fewer trees, shrubs, and other plants to shade buildings and cool the air through transpiration. As temperatures rise, more cooling energy is required to maintain comfort levels in buildings. Higher urban temperatures often increase the instability of the atmosphere, and therefore the chance of rainfall and severe thunderstorms. The city of Cologne, Germany, for example, receives 27 percent more rainfall than surrounding rural areas (Peck et al. 1999, 24).

On a warm summer day, plant absorption of the sun’s energy lowers the temperature of the surfaces below or shaded by the vegetation, as well as regulates humidity (Peck et al. 1999, 21). The impact of evapo-transpiration and shading could reduce the amount of heat that would normally be re-radiated by the building. As Virginia Gorsevski, program analyst with the U.S. Environmental Protection Agency’s office of Air and Radiation, points out though, nobody knows how many roofs would have to be resurfaced or trees planted to make a measurable difference in urban heat islands (Webber 1999).

Air Quality

Hotter temperatures also contribute to ground level ozone, or smog, in the presence of the pollution as they increase the photochemical reactions responsible for ozone creation. By
cooling ambient air temperatures, smog and energy loads could be reduced, as well as the associated health and social costs. William Abolt, acting commissioner of the City of Chicago’s environmental department, believes that reducing emissions from vehicles and unregulated businesses, or cracking down on industrial smokestack emissions won’t be enough. Hashem Akbari, a researcher at Lawrence Berkeley National Laboratory in California, agrees. “Based on modelling and results of small-scale testing, cooling a city could reduce smog more than almost every other pollution-fighting measure” (Webber 1999).

Green roofs also help to improve urban air quality by filtering airborne particulates, and converting carbon dioxide into oxygen through the process of photosynthesis. Using figures generated in Minke & Witter’s book *Haeuser mit Gruenem Pelz, Ein Handbuch zur Hausbegruenung*, the *Greenbacks* report suggests that one square metre of grass roof can remove about 0.2 kilograms of particulates from the air every year, and 1.5 square metres of uncut grass produces enough oxygen per year to supply one person with their yearly intake requirement (Peck et al. 1999, 25). The report also notes, though, that it is important to consider the following when evaluating the contribution of urban greening to the production of oxygen: (1) plants only produce oxygen during the day, at night they take in oxygen and give off carbon dioxide (there is, however, a net increase in oxygen); (2) in most Canadian climates, many plants are dormant during the winter and therefore do not produce oxygen or carbon dioxide; (3) the decomposition of organic matter—on top of, or within the substrate—requires oxygen; (4) if the plant/grass layer is allowed to dry up during the summer it cannot produce oxygen (Peck et al. 1999, 26).
BUILDING INSULATION

Thermal

The role of insulation is to slow down the rate of heat transfer between the inside and outside of a structure. In the winter this translates to slowing the rate of heat transfer to the outside, and in the summer, the rate of heat transfer to the inside (Peck et al. 1999, 22). Many advocates of green roofs illustrate the potential benefits of the technique by pointing out how it contributes to the thermal insulation of a building. The type of plants used, the depth of the growing medium, and the system’s moisture content determine the insulation value. A layer of mixed grass appears to insulate better than a layer of limited-species grass, which in turn performs better than low-growing sedum (Peck et al. 1999, 23). The Greenbacks report suggests that there are three ways vegetation increases the insulation value of the roof: (1) trapping a layer of air within the plant mass cools the roof’s surface in the summer and warms it in the winter; (2) covering the roof with vegetation prevents summer heat from reaching it; and (3) a plant layer can act as a buffer that keeps wind off the roof surface (Peck et al. 1999, 22).

A number of articles and research propound to support these assertions. Kölb’s 1986 article noted the markedly reduced temperature fluctuations with roofs covered with vegetation compared to those covered with gravel (10). Swiss research suggests that buildings with roof gardens lose up to 30 percent less heat during the winter depending on the soil and vegetation used (Port Phillip EcoCentre). Finally, the Greenbacks report asserts that a 20 cm (8 in) layer of substrate covered with a 20-40 cm (8-16 in) layer of thick grass has an insulation value equivalent to 15 cm (6 in) of mineral wool insulation (R20) (Peck et al. 1999, 23).

3 Utilizing a green roof does not preclude the installation of standard building insulation. A green roof is essentially installed on top of a conventional roofing system. (See Construction).
As Nico Hendricks points out in his article “Designing Green Roof Systems: A Growing Interest,” though, this notion that green roofs provide exceptionally good thermal insulation must be put into perspective. During the winter when thermal insulation is of primary importance, there is often more precipitation and evaporation, which means that the materials lying above the waterproof membrane may be continuously wet. As such, Hendricks doubts that green roofs contribute to thermal resistance under winter conditions (Hendricks 1994, 22).

Unlike winter, during the summer the influence on heat flow can range from moderate to substantial depending on the thickness of the various layers and the mass of the substrate (Hendricks 1994, 22). Shading the external surface of a building envelope has been shown to be more effective than internal insulation. On a summer day, the temperature of a gravel-covered roof can increase by as much as 25-80°C. Covered with grass, the temperature of the same roof would not rise above 25°C. This has a direct effect on the interior climate conditions. Rooms under a green roof are generally 3-4°C cooler than the air outside, when outdoor temperatures range between 25-30°C (Green Roofs for Healthy Cities).

Due to the dependence on vegetation and substrate depth, eco-roofs likely contribute negligibly to thermal resistance. Although their insulating properties are small, they can however, increase the thermal efficiency of a building by acting as a buffer to extremes of climate (Nature Conservancy Council 1990, 17). In the summer, eco-roofs prevent solar radiation from striking the roof membrane, and in the winter they protect the roof from heat loss due to wind. Even though the specific R-values of green roofs fluctuate depending on the amount of moisture in, and on the growing medium, and researchers have yet to provide standard and approved insulation ratings for them, this has not stopped German researchers from promoting these insulating qualities (Peck et al. 1999, 24).
Acoustical

The extent to which green roofs can provide acoustical benefits is highly dependent on the mass of the substrate layer and on existing sound leaks, such as skylights (Hendricks 1994, 22). Sound waves can be absorbed by the soil, plants and, trapped air layer on a roof. The substrate tends to block lower sound frequencies and the plants block higher frequencies. The Greenbacks report suggests that a green roof with a 12 cm (5 in) substrate layer can reduce sound by 40 decibels, and one with 20 cm (8 in) of substrate can reduce it by 46-50 decibels (Peck, et al. 1999, 30). The particularly shallow nature of eco-roofs no doubt compromises their ability to mitigate acoustic disturbances.

STORMWATER MANAGEMENT

In the natural water cycle, rain soaks into the soil and is slowly released by evaporation and transpiration, or percolates down to the water table. Impervious surfaces such as roofs, streets, parking lots, etc., alter this cycle by diverting a majority of the rainfall to stormwater drainage systems (Port Phillip EcoCentre). Engineering for urban development has traditionally focused on moving rainwater and melting snow away from buildings and roads and into constructed stormwater systems. According to Toronto and Region Conservation Authority studies, “approximately 25% of land area in new subdivisions in Canada are paved and non-porous” (Peck et al. 1999, 27). Problems associated with stormwater runoff include:

- The contamination of stormwater. Rainwater picks up a variety of pollutants as it runs over impermeable surfaces—grease, oil, and particulates—before it reaches storm drains. In a number of cities, stormwater represents the largest contributor to water pollution in local rivers.
- Combined sewage overflows (CSO). A number of older cities—Vancouver, Portland, Seattle, etc.—still utilize older combined sewer systems that carry both sewer and stormwater. During heavy rainfall these systems can overflow causing diluted raw sewage to be discharged into local streams and rivers.
• Drop in local water tables and the base flow of streams and rivers, as the majority of natural precipitation is directed to and discharged into major bodies of water rather than infiltrating into the ground.

Cities have typically addressed stormwater volumes by: (1) enlarging or expanding stormwater infrastructure to accommodate greater volumes of water, an often costly and disruptive process; or (2) using 'end of pipe' solutions such as directing flows to large, temporary storage facilities or retention ponds. In some cities, such as Vancouver and Toronto, engineers have recently begun initiating a number of projects aimed at addressing stormwater concerns at the site level. Rain barrels or small cisterns represent an on-site version of larger, central storage facilities, with the additional benefit of providing water for later yard maintenance. The disconnection of building downspouts where suitable pervious surface is available, the installation of swales adjacent to parking lots to catch runoff, and the use of porous pavement are all aimed at reducing peak flows by increasing rainfall absorption and retaining water on site (Peck et al. 1999, 27).

Where the above measures mitigate stormwater at grade, green roofs address and utilize the vast acres of impervious roofscape to effect runoff quality and quantity.

Quality

The ability of green roofs to affect the quality of stormwater by filtering the rain depends on the composition and depth of each layer of the system, both individually and collectively. The capacity of various soil compositions and different types of vegetation to filter any number of pollutants from stormwater represents an area of study beyond the scope of this paper. The limited research on green roofs regarding this subject does suggest, though, that heavy metals and nutrients carried by the rain become bound in the substrate instead of being discharged.
Studies show that up to 95 percent of heavy metals such as cadmium, copper, and lead, and 16 percent of zinc have been taken out of rainwater by green roofs (Johnson and Newton 1996, 12).

**Quantity**

Retaining a percentage of the precipitation that falls on them, green roofs reduce stormwater runoff and therefore help alleviate potential flooding problems and combined sewer overflows (CSO's). Green roofs mimic the processes that occur in nature, intercepting and delaying rainfall runoff. They capture and hold precipitation in the plant foliage, absorb water in the root zone, and slow the velocity of direct runoff as it infiltrates through the layers of vegetated cover (figure 4.3) (Roofscapes Inc.).

The amount of water retained by a system depends on the time of year, the depth of the soil and drainage layer, and the slope of the roof (figure 4.6). In Switzerland, extensive green roofs retain 70-100 percent of summer rain and 40-50 percent of the rain in the winter, when the soil is already moist (Port Phillip Eco-Centre). Research has found that a grass covered roof with a 20-40
A 90x716 cm (8-16 in) thick layer of substrate can hold between 10-15 cm (4-6 in) of water (Peck et al. 1999, 28). The Greenbacks report speculates that in Toronto, where the average rainfall event is 4 cm (1.5 in), a green roof could certainly become a viable stormwater management option. A three month long summer study in Europe showed that even an extensive roof with only a 7 cm (3 in) vegetation layer produced no runoff, while the soil surface at grade, without planting, produced 42 percent runoff and a gravel surface at grade produced 68 percent runoff (Peck et al. 1999, 28). In sufficient numbers green roofs could significantly reduce runoff from built-up areas and in doing so, save on drainage installation costs (Port Phillip Eco-Centre). Roofscapes Inc., a green roofing company in Pennsylvania argues that “the deployment of vegetated roof covers may offer the only practical "at-source" technique for controlling runoff in areas that already are highly urbanized.” It notes that due to their potential for addressing flooding impacts in urban areas, vegetated roofs were mentioned in the recently published Pennsylvania Handbook for Best Management Practices in Developing Areas (Roofscapes Inc.).

Tom Liptan, an engineer with the City of Portland Bureau of Environmental Services (BES) in Oregon, in an effort to investigate the rainfall retaining capabilities of green roofs in Portland, installed an eco-roof on the 10 x 18 ft (3 x 5 m) roof of a small, unheated building. For waterproofing he used inexpensive plastic sheeting over which he placed two inches of on-site soil mixed with compost. In this he planted a variety of sedums. Following the first storm of
0.4 in (1 cm) of rain (approx. 40 gal [151 l] of rainwater on the 180 ft² [17 m²] roof) only 3 gal (11 l) of runoff reached the ground. Following the next storm, 2 in (5 cm) of rainfall continued to flow from the roof, slowly, for two days. He found that during subsequent periods of heavy rainfall his eco-roof was less effective in absorbing rainfall; overall, however, it did retain 15-90 percent (depending on the intensity) of the rain that fell on it (Beckman, et al. 1997).

This propensity for retaining stormwater motivated Toronto’s York University to install a green system on the roof of its new Computer Science Building. Flat roofs on different levels, as well as a sloped surface of 10 degrees, will provide an inaccessible wildflower meadow that is expected to help reduce the evacuation of stormwater, some of which will be stored in basins on the roof (Gillies 2000).

CONCLUSION

The purported benefits and potential impacts of eco-roofs are indeed numerous. Whether or not these benefits justify the additional costs associated with their installation and potential maintenance, though, depends a great deal on the region where they are implemented. For example, while eco-roofs may prevent solar radiation from striking the roof, and as such protect the roof and reduce interior temperatures, in regions with limited solar exposure, this ability has little applicability. However the same region may possess stormwater issues that make an eco-roof’s rainwater retaining capacity an important and viable contribution. Regardless, in order to receive the benefits of eco-roofs, one must properly design and construct the roof to suit the needs of the building and its environment. In the chapter to follow the thesis will discuss the general components and materials used in green roof construction.
CONSTRUCTION

The construction and success of eco-roofs depends on the specific needs and conditions of a site. Wind, temperature, moisture regime, and sun exposure can vary considerably from project to project. Eco-roofs are generally comprised of five or six components including, from the roof deck up: a waterproof membrane; an optional layer of insulation or a protective layer; a drainage layer; the growing medium, also referred to as ‘substrate’; vegetation; and in some cases an irrigation system (figure 5.1). Many of the problems associated with green roofs stem from the faulty installation of one or more of these layers and/or careless maintenance practices. In no other landscape element is the relationship between design, construction detailing, and long-term maintenance so interdependent.

Over the past 30 years, a number of roofing membrane companies have designed complete intensive and extensive systems, including specialized drainage layers, scientifically formulated, lightweight growing mediums, and growing mats impregnated with seeds. The following portion of the thesis looks to review, at a relatively broad level, the components of eco-roof construction. This section should not be considered a comprehensive review of the systems presently available, but rather a general synopsis of the materials and conditions typically required.

5.1 Cross section of a typical green roof (Roofscapes Inc.).
BUILDING CODES AND REGULATIONS

Unlike Germany and several other European countries, which strictly regulate the manufacturing of materials used for green roofs, as well as the construction process, neither the National Building Code of Canada, 1995 or the Building Code of British Columbia, 1998 discuss roofing materials beyond those used in conventional membrane and roof assemblies. These building regulations, as well as those in the Vancouver Building By-law, 1999, merely require that the selected materials meet performance standards and provide the necessary protection from precipitation.

The roofing membrane guarantee issued by the Roofing Contractors Association of British Columbia (RCABC) also does not preclude the installation of green roofs. So long as the membrane’s manufacturer guarantees their work and the building owner accepts responsibility for and the associated costs of removing the green roof in the event of membrane failure, the RCABC will guarantee the roof (Altizer 2000).

ROOF SLOPE

Contrary to popular belief, and as evidenced by historical examples, eco-roofs do not require low-slope (often referred to as flat) roofs as do conventional roof gardens but may be installed on roofs with slopes of up to 45 degrees. A low slope is desirable, though, for both intensive and extensive systems in order to slow the flow of water from the roof. Pitched roofs require special considerations including raised grids to prevent the substrate from slipping, and for slopes greater than five degrees, it might be necessary to compensate for rapid runoff by increasing the retention capacity of the substrate. As low-slope systems comprise the majority of green roof installations, the following chapter assumes minimal slopes in its discussion.
STRUCTURAL/LOAD BEARING

Developers and contractors often regard the production of roof gardens with apprehension because of the extra weight that they add. Structural engineers divide loads into two categories: dead loads and live loads. The dead load refers to the weight of the roof structure itself and any permanent functional elements. The live load, on the other hand, includes elements such as human occupants, snow, rain, maintenance equipment, and other items of a transient nature. Regardless of how light a green system may be, the provision must be made for both the weight and dimensions of equipment and material which may be used at various stages of construction and maintenance of the roof (Nature Conservancy Council 1990, 10).

The first issue concerning loads is whether a building is being designed for a green roof or is being retrofitted. In new construction, the roof's structural system can be designed from the outset as required with relatively little additional cost (Taylor 2000). Retrofitting, on the other hand, can be more difficult and quite costly. Architects and engineers generally design buildings to meet regionally specific codes, with little allowance for additional roof loading. As such, retrofitting, as well as structural redesign prior to construction, can increase costs substantially. The Mountain Equipment Co-op's 903 m$^2$ (9,720 ft$^2$) green roof in Toronto required structural redesign to accommodate its eco-roof. Labour and materials for the roof cost $115,000 ($12 sq/ft) however, the structural upgrade (redesign) of $55,000 added another $5 per square foot (Peck, et al. 1999, Appendix II).

The fundamental requirements for green roof design include achieving a maximum planting effect using minimum organic support and spreading the weight load over a wide area (Funke 1992, 46). In concept, eco-roofs are lightweight, modern versions of the sod roofs of Scandinavia. Proponents of eco-roofs assert that these system's light weight generally requires
little additional load-bearing capacity from most buildings' structural systems, and in some cases may be installed on existing buildings with no structural modification. There are a number of green roofing system manufacturers that suggest that extensive landscape systems need not be heavier than the gravel covering used on some roofs. According to Kölb’s article in Anthos, a German landscaping and landscape architecture journal, the majority of low-slope roofs in Germany are covered with gravel (approximately 5 cm [2 in]), which has a load of about 100 kg/m² (20 psf) (5). Using this load as the guideline for an extensive system, Kölb suggests that many gravel roofs might be greened, without additional load reserves. While studies have shown it possible to replace the gravel layer of gravelled flat roofs with a green roof system equivalent, much of this research relates specifically to European building standards and load requirements. When applied to North America, gravel protected or ballasted roofs use 1-5 cm (0.4-2 in) of gravel, depending on the membrane, constituting a load of approximately 20-100 kg/m² (4-20 psf). This makes the widespread replacement of gravel with eco-roofs far less feasible. There are however, foam systems, developed for low-cost green roofs, that weigh as little as 25-30 kg/m² (5-6 psf) with maximum water uptake, as well as pre-planted roofs, with small meadow flowers and grasses or pre-turfed roofs with loadings of 82 kg/m² (17 psf) and 66 kg/m² (13.5 psf) respectively. The latter can be compared to concrete roofing tiles, which have a dead load of 70 kg/m² (14 psf) (Nature Conservancy Council 1990, 15; Vale 1991, 149).

COST

Capital

Costs for creating and maintaining an extensive green roof are generally much less than those for an equivalent area of intensive roof garden. Some estimates suggest that costs could be
reduced by 50 percent or even as much as 80 percent by using an extensive rather than intensive system (Johnson and Newton 1996, 72). This reduction is attributed to the reduced need for structural reinforcement, smaller quantities of materials, and fewer maintenance requirements.

There is some disagreement, though, as to the average capital costs of eco-roofs. Johnson and Newton and Steven Peck assert that if planned from the outset, they can be included in the design of a building at little or no extra capital costs (Johnson and Newton 1996, 72; Peck, et al. 1999, 16). While costs associated with additional loading requirements might prove minimal if included in the initial planning of the building, the application of several layers of materials above and beyond a conventional system inevitably creates a difference in the ultimate cost of the roof. Where a conventional roof will range between $1.50 and $10 per square foot depending on the roofing material, the eco-roofs manufactured and installed by green roofing companies typically range between $8 and $20 per square foot, depending on the system and more importantly the vegetation that is used. This is two to four times the cost of a middle-range conventional roof per square foot.

According to Marie-Anne Boivin, the cost of the Sopranature system, manufactured by Soprema Canada, varies depending on the type of vegetation desired and the amount of work required to install the system. Initial costs usually fall between $8 and $13 per square foot (Tynan, 1998, 2). The patented built-up systems produced by membrane companies such as Soprema, Erisco Bauder, Optima, Garland are more expensive than do-it-yourself versions as they include layers—soil mixtures, drainage mats; etc.—specifically developed (and marketed) for the roof. While they are convenient, systems of comparable quality can be designed and installed by qualified professionals for considerably less.
A rough cost-analysis done by Katrin Scholz-Barth, Director of Sustainable Design for the HOK Planning Group in Washington, D.C., on a theoretical eco-roof illustrates how a do-it-yourself system might compare to a conventional roof. Scholz-Barth suggests that an extensive system might cost only about one third more than the same roof without vegetation. Scholz-Barth notes that if the potential energy savings from the insulation and a longer lifespan for the roof are taken into account, the annual cost over the lifetime of a green roof may be only half that of a conventional assembly. A conventional roof costing $100,000 with a lifetime of 24 years has an annual depreciation of $4,200. A similar greened roof would cost about $135,000 (material costs plus installation), last about 36 years and provide an energy savings of $70,000, giving an annual depreciation of $1,800 (Port Phillip EcoCentre; Scholz-Barth 2000). While the above figures do not address the issue of roof replacement, assuming no complications arise and given the current lifespan of buildings, a structure would, more than likely, be taken down before the eco-roof would need to be replaced. It is important to note, though, that if the eco-roof required replacement, as in the case of membrane failure, it would be considerably more costly than a conventional roof. Regardless, for developers who are looking to build and sell quickly, even a nominal increase in the initial price can be seen as a barrier unless they feel it will make the property more marketable.

**Maintenance**

Conventional roof maintenance generally entails annual inspection of the membrane, and in particular locations of any projections through the membrane such as ventilation and exhaust stacks or HVAC equipment, as well as edge details. This typical maintenance of the membrane becomes essentially impossible after installation of the eco-roof. Great care must be taken in
both the selection of roofing materials and the construction of the system, as problems prove exceptionally difficult to find and costly to repair compared to conventional roofs (Crocker 1986, 7).

Maintenance costs for the vegetated portion of a green roof vary in accordance with the objectives of the project. Eco-roofs are ideally designed to require little maintenance, perhaps watering during severe drought and the removal of tree seedlings, autumn leaves, and the occasional weed several times a year (Johnson and Newton 1996, 70; Tynan 1998, 2). A low-maintenance landscape is best achieved through a naturalistic approach. Less formal and more naturalistic gardens require less attention, ultimately reducing maintenance costs. Flower-rich meadows thrive on nutrient-poor soil whereas traditional lawns require periodic additions of fertilizer. The grass on the visitors' centre at Martin Mere in England is not mown but rather allowed to grow and die back naturally each year. The only management consists of occasionally weeding out invasive plants such as ragwort and thistle (Johnson and Newton 1996, 71). The maintenance on France’s largest expanse of roof greening, the 6,503 m² (70,000 ft²) meadow on the international school complex of Lyon-Gerland, has so far been limited to the annual removal of dried vegetation (Osmundson 1999, 33).

There are those who feel, though, that regardless of the type of green roof used, in a closed system, maintenance requirements are the same if not more than those landscapes at grade. Neglect can prove detrimental to the survival of a green roof. The most common causes of plant failure in roof gardens are moisture stress, deoxygenation when the drainage fails, or nutrient stress when plantings don’t have adequate fertilizer (Port Phillip EcoCentre). The implementation of vegetation free zones can help facilitate maintenance. These zones improve fire safety and roof drainage; reduce the development of undesired shoots; ease the inspection
and repair of the edge connections in the roof system; and provide footpaths for vegetation maintenance.

Designers often underscore accessibility of the roof to maintenance personnel. For even modest maintenance requirements, special care must be taken to insure ready access for landscapers, gardeners and their respective equipment. While some green roofs have been in place for 50 and 60 years without requiring major repairs or replacement of soil or plantings, there is always the possibility that these or other elements may need addressing. Vancouver Public Library's green roof was originally designed to require little or no maintenance, irrigation or fertilizing, however for at least a year now VPL gardeners have needed to tend to it weekly to deal with weeds, losses in soil volume, and deteriorating plant quality. Approximately 75 percent of the library's monthly gardening fee (roughly $1,500) is spent on the roof alone. The design of the building has made this maintenance difficult, as access to the roof is extremely awkward and somewhat dangerous (Anonymous 2000).

LAYERS

A green roof consists of several layers of materials. The selection and installation of these layers usually falls under the responsibility of the project architect, in consultation with a structural engineer, landscape architect, roofing contractor and the client. The sequence of the

5.2 Low-slope roof with insulation placed in three positions. Left: cold roof construction, insulation is placed below the roof deck with a ventilated airspace in between. Middle: warm roof construction, insulation is installed between the deck and membrane. Right: protected membrane roof (inverted), in which the insulation laid above the membrane. (Allen 1999, 569)
layers can vary depending on the construction of the building. Cold, warm, and inverted (protected membrane roof [PMR]) roof construction can be used with eco-roofs, however the first two are more common (figure 5.2). The following discussion assumes the insulation is below the membrane and looks at those layers typically used in green roof construction.

Membrane/Water Proofing

The waterproof membrane layer should ideally be flexible, have good tensile strength, and be easy and efficient to join. Three coats of mastic asphalt and felts (alternately known as a built-up-roof [BUR]) form the most common construction used in Britain, however in Canada and the U.S. the most frequently used materials include reinforced PVC, EPDM, or modified bituminous material (SBS). While asphalt is an organic material and therefore subject to decomposition, there are 60-year-old green roofs constructed atop BUR’s—Derry & Toms in London (1938), the Rockefeller Center in New York (1936), and Union Square in San Francisco (1942)—that have had no problems with leaks or other membrane failures (Osmundson 1999, 158).

Close supervision of workmanship is vital to avoiding defects that will be hidden by the soil. Particular care must be taken to ensure a good seal around any penetrations, which should be avoided whenever possible. In addition to roof penetrations, structural movement joints are likely points of failure and no planter or roof garden should be designed so that the joint is covered by soil. The membrane should be tested prior to the installation of other layers by plugging all rainwater outlets and then flooding the roof.

Protection

There is often concern that the roots of the plants might penetrate the roof membrane. While Scrivens argues that roots cannot ‘drive’ through a continuous layer of waterproof
membrane (Scrivens 1982, 76), it is advisable to protect any membrane against accidental
damage, particularly physical damage during construction and from future gardening. The
simplest form of protection involves placing paving slabs (although not usually appropriate for
single-ply membranes), protection board, or a protective cement sand screed directly on the
membrane (Scrivens 1982, 76). Extensive roofs often have a layer of PVC as protection against
the unlikely penetration of roots. The PVC layer is then covered with a layer of felt to help
anchor other layers and protect it from mechanical damage (Johnson and Newton 1996, 57). An
advantage of an inverted system is that the insulation above the membrane can also act as
protection.

**Drainage**

Appropriate drainage constitutes a vital component of green roof construction. If the
moisture content in the substrate remains too high, then there could be a danger of root disorders
(i.e. root rot) due to the activities of plant pathogens (Scrivens 1982, 77). Two approaches to the
drainage layer are as follows:

1. The roof is sloped to drain naturally. Water percolates into the soil and then through a
granular base material. Certain extensive green roofs will not need a drainage layer if the
roof slope is five degrees or more and the vegetation does not exceed 25 cm (10 in) in height
(Johnson and Newton 1996, 58).

2. Retain water on the roof using a half-hydroculture system, which involves partial saturation.
Half-hydroculture systems require considerably less irrigation, as rainwater is retained over
the main body of the roof; it rises up through the planting medium via capillary action.
Optima, one of the most widely used systems in Europe, contributes up to 150 kg/m² (31psf)
to the live load (Scrivens 1982, 77; Osmundson 1999, 181).

A variety of materials and depths can be used for the drainage layer depending on how
little or how much water is to be retained on the roof. The first drainage materials used in
modern times consisted of pebbles, broken rocks, and crushed brick. More recently, drainage
Materials have included LECA (light expanded clay aggregate), pea gravel, plastic foams, and even old tennis balls (Scrivens 1982, 78; Nature Conservancy Council 1990, 18). In tests at Veitshöchheim, apart from a relatively heavy gravel layer, porous materials from lava, and clay granulates proved quite effective at storing 30-40 percent of their volume in water (Kölb 1986, 6). Woven thread drainage mats are an option when water retention is not necessary or desirable. The mats contribute virtually negligible weight to a system, and give an additional mechanical protection to the protective membrane.

A number of speciality drainage products have been developed in the past 30 years, including a variety of premoulded synthetic elements (Hendricks 1994, 23) (figure 5.3). Plastic foam materials are popular in Germany, Holland, and Belgium where they have an expected life span of at least 25 years and can retain up to 80 percent of their volume in water.

Regardless of the system used, carefully planned drainage points will be needed. While some people feel drains can be either totally hidden below the substrate (figure 5.5) or visible, to readily facilitate maintenance, Hendricks insists that it is essential that they are recognizable and accessible from the

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5.3 Premoulded drainage layer manufactured by Zinco (Zinco GmbH 1998).

5.4 Sectional elevation of a specially designed outlet used at Gateway House in London. It drains at membrane level and can be accessed above and below (Scrivens 1980, 446).
top (figure 5.4). He notes that they should be fitted with a basket construction and cleaned at least every season (Hendricks 1994, 23). Drain design should permit water “to flow into the top at ground-surface level as well as through the sides of the drain below the surface” (Osmundson 1999, 167). This allows water runoff from the surface and subsurface drainage layer. Great care should be given to the placement of these drainage points, and all outlets should have protective filters to stop soil from being washed down (Scrivens 1982, 78; Scrivens 1980, 445). In order to drain water properly, it is of vital importance that the substrate has a slope of at least 1:50 (2%) with 1:25 (4%) preferred. The drainage capacity must increase closer to the actual drains, and it is important to install large quantities of drainage material along the eaves and near the outlets (Hendricks 1994, 23).

**Filtration**

Water, passing through the planting medium to the drainage system, often carries with it bits of soil, mulch, and plant debris. If this water is not filtered, not only will valuable planting medium be lost to the building’s drainage system, but also the drains themselves can become clogged. Traditionally, this filter layer has consisted of a glass fibre mat up to 50 mm thick. This layer was then covered with a 50-mm layer of peat in order to improve filtering and the storage of moisture. With the introduction of more durable filtration materials, such as polypropylene and polyethylene fibre mats, this peat layer is no longer necessary (Scrivens 1982, 78). The filter layer must be installed carefully, with overlaps of at least 10 cm (4 in). It must be
folded up along all vertical edges, just above the top of the substrate, and finished with a strip of self-adhering bitumen membrane (Hendricks 1994, 23).

**Substrate/Growing medium**

The soil used for green roofs remains one of the least understood elements of the system. The special needs and conditions of these landscapes, which require strong, light, long lasting, stable, and inexpensive soil, can be confusing to the designer. In the search for appropriate growing media, some European systems have eliminated soil altogether. Climate, location, and the prospective plant species all influence soil selection (Johnson, J., Newton, J., 1996). Traditional substrate material, topsoil mixed with such materials as expanded polystyrene, ‘LECA’, perlite (a variety of obsidian), bark, or peat, has not proved particularly successful due to infestations of weed seeds (Kölb 1986, 8).

Plants appropriate for extensive roof systems tend to favour nutrient poor soils, therefore materials that improve the soil structure without enriching it perform best: bark, leaf mould, perlite, etc. (Port Phillip EcoCentre). A bare bones approach involves using sand, covered with a porous erosion-control fabric, and planted with stonecrop, a variety of sedum used in Berlin (Johnson and Newton 1996, 61). In Europe seed mats, foam substrates and drainage mats have been developed for low-cost, low-weight, roof planting (Nature Conservancy Council 1990, 20). Regardless of the hardiness of the plant, though, correction of nutrient deficiencies is extremely important. Certain species may require the addition of composted material, or the equivalent, for extra nutrients.

Low-maintenance, extensive systems rely not only on the substrate’s capacity for water storage but also its permeability. The ideal soil creates unfavourable conditions for undesirable plants, as well as provides an optimal growing medium for the specific species to be planted.
Given the potentially conflicting effects of these conditions, one is unlikely to fulfil all the requirements (Kölb 1986, 8).

While soil depth can be as little as several centimetres, it is generally desirable to have as large a volume and depth as possible to contribute to wind stability and offset high drying rates (Port Phillip EcoCentre). Boivin and Challies recommend that the minimal substrate thickness (5 cm) used for extensive systems in Europe be increased to 8 cm (3 in) in northern regions, in order to minimize winter damage. Studies by Marie-Anne Boivin, while at the Horticultural Research Centre at Laval University in Quebec City, found that there was less winter damage in plants grown in 10-15 cm (4-6 in) of substrate compared to 5 cm (2 in). Deeper substrates (15 versus 5 cm) also proved beneficial during the summer months, resulting in a general increase in growth (Boivin 1997, 379). Thicker substrates provide greater volume in which plants can expand. This enables root systems to better establish themselves, resulting in more extensively developed aerial systems and the increased ability to resist adverse weather conditions (Boivin 1997, 380).

Roofs with higher than usual exposure often elicit concern about the stability of the substrate. If the planting medium is particularly sandy or peaty, and allowed to become too dry, then wind erosion may occur. Soil movement due to wind and/or rain, however, is generally minimal (Scrivens 1982). Over time, the substrate will experience losses in volume not only due to natural settling processes, but also through the removal of material during normal maintenance. Substrate mixtures with higher organic content tend to suffer a further reduction in volume through mineralization (the breakdown of the organic compounds) (Kölb 1986, 8).
Vegetation

One of the greatest challenges of growing plants on top of a structure comes from the landscape's high degree of exposure. The natural environments that most closely match roof garden situations are coastal plant communities (Port Phillip EcoCentre).

Growing Conditions

Wind—Wind has a drying effect on plants and soils, and can also erode the substrate, particularly before ground cover becomes established. Strong winds can uproot or damage vegetation that has not been adequately protected (Johnson and Newton 1996, 51). It is not uncommon for wind speeds at roof level to be more than double those experienced at grade (Scrivens 1982, 74). Wind can sometimes be moderated using the configuration of the roof in the careful placement of mechanical equipment, vertical lift units, parapet walls, or other building projections (Johnson and Newton 1996, 51).

Temperature—While preliminary readings indicate that it is common for winter soil temperatures of a roof garden to be at least 5°C if not 10°C higher than those in the surrounding landscape, thin soils on the roof tend to freeze more easily than deeper soils on the ground (Scrivens 1982, 75). The opposite effect occurs during the summer when rooftop soil temperatures can be up to 5°C higher. Temperatures can also vary across a roof. Summer air temperatures have been found to be 1-5°C higher on the south slope of the roof, resulting in a warmer substrate. In the winter, though, temperatures were similar across the roof regardless of slope (Johnson and Newton 1996, 52).

The building's internal climate also affects rooftop vegetation. 'Bottom heat' from a building can, on the one hand, cause plants to come into leaf and to flower several weeks before
the same plants at ground level, as well as extend the growing season. On the other hand, though, it can have a negative effect on plants normally dormant during the winter.

*Moisture*—Due to thin substrates and increased exposure, there is often rapid fluctuation between saturation and drought. Water loss is a particular concern between May and September. During these months some form of artificial irrigation may be needed. The need for irrigation can be modified, to some extent, for extensive green roofs by planting drought resistant species, or by incorporating rainwater-fed water storage sumps at roof level in the form of tanks or open pools (Johnson and Newton 1996, 52).

**Plants**

Through studies of spontaneous vegetation on unplanned green roofs, a picture of suitable plants for extensive systems begins to emerge. Appropriate species include a vast array of native and traditional garden plants. Native species, adapted to the local climate and conditions, typically require less maintenance—rarely need fertilizers, prove less susceptible to pest attack and drought, and generally require less management—and prove better able to provide the food needed by wildlife. Turf and vegetation from wasteland areas (sites designated for destruction through development) and those covered with low-growing ruderal (a plant that grows on waste land) vegetation can provide suitable roof coverage. Mosses are particularly favourable as they easily cover large areas, store moisture, survive drought, add little weight to the roof, have minimal nutrient requirements, display a good tolerance of pH levels and are tolerant of a wide range of light levels (Johnson and Newton 1996, 64-66). Other plants appropriate for extensive systems include:
- Succulents and other ‘opportunists’ that create roof gardens requiring minimal maintenance.
- Alpine species, as they are resistant to wind damage and can flourish in shallow soils.
- Climbing plants, which are lightweight, cover large areas, and whose roots take up little space (Nature Conservancy Council 1990, 23).

**Irrigation**

Easy access to an irrigation source is needed for every green roof, even if only for initial watering or during periods of severe drought. The provision of irrigation, whether it is a system installed on the roof or a simple garden hose and sprinkler unit run from below, involves additional costs (both in capital and in maintenance) above and beyond basic green roof installation. This potential need for irrigation is a particularly important consideration for those regions with limited water resources, or where water usage charges apply.

While extensive green roofs generally do not require irrigation, except under prolonged dry conditions, their inability to access groundwater and high exposure makes evapotranspiration losses considerably higher than at ground level. Selecting plants that tolerate arid conditions reduces the system’s dependence on irrigation. Many plants have growth forms and other means of protection for surviving prolonged dry spells. Plants generally have low growth forms and a high root-to-shoot ratio when moisture is limited, and may stop growing in the summer until rain returns in the autumn. Both succulents and mosses lie dormant when water becomes scarce.

One of the most reliable irrigation control devices for roof gardens is the use of moisture sensors in the substrate. These are pre-programmed to operate a solenoid valve and irrigate once the soil dries out to a given value (Port Phillip EcoCentre). Whether the irrigation system is manual, or partially or fully automated, the value of a moisture-sensing device such as a tensiometer cannot be overstated (Nature Conservancy Council 1990, 12).
CONCLUSION

The number and variety of green roofing systems and materials available today, as well as their respective costs, can be somewhat overwhelming and confusing. The above chapter only briefly reviews the fundamental components of eco-roof construction. Ultimately, the selection of materials relies on the specific characteristics, limitations, and objectives of the project. It is imperative that great care be taken in selecting and installing the materials. Sixty-year-old, problem free rooftop gardens do exist, however others of more recent construction have failed. Poor workmanship and damage during construction can compromise the best of intentions. Constant inspection, during the roof's installation, by knowledgeable consultants—a representative of the membrane's manufacturer, a roofing consultant, a landscape architect, etc.—is of the greatest importance to the successful performance of the roof. In the next chapter, the thesis will discuss what role well designed and constructed eco-roofs might have in Vancouver and the surrounding region.
ECO-ROOFS AND VANCOUVER: A CRITICAL ANALYSIS

Located in the southwestern corner of Canada, Vancouver represents the largest city in the province of British Columbia, and the third largest in Canada. Approximately 40 kilometres north of the U.S. border, it is surrounded on three sides by water: the Burrard Inlet to the north, the Straight of Georgia to the west, and the north arm of the Fraser River to the south. Covering 114 square kilometres, Vancouver has the second smallest area of the eight largest Canadian cities. The 2,787 square kilometre metropolitan area, though, is the third largest in Canada. During the census period 1991 to 1996, Vancouver’s population grew by approximately 42,000 people or almost nine percent. During this time, the Greater Vancouver Regional District (GVRD) (Appendix I) proved the fastest growing metropolitan area in Canada at 14.3 percent, more than twice the national average. The region has almost doubled its population in the last 30 years and is predicted to grow another 40 percent by 2021 (GVRD). Despite this considerable growth, in 1995, the Corporate Resources Group in Geneva, Switzerland, ranked Vancouver the second best city in the world and first in North America based on living and environmental conditions. Later, in 1997, the same group rated Vancouver as the most liveable major city in North America and the world (City of Vancouver 1998). Unfortunately, if development proceeds status quo, the region’s growth will cause irreparable damage to the remarkable natural area that houses it and for which it is famous.

In Europe, over 25 years of research and widespread green roof implementation have demonstrated the ability of rooftop vegetation to help mitigate the ill effects of urbanization. Limited space, higher densities, and a different sociological outlook have motivated many European countries to aggressively pursue environmentally responsive design, consequently
supporting the growth of green roofs and related industries. In Coastal British Columbia, and
more specifically Vancouver and the GVRD, people face an entirely different array of
environmental conditions and issues. While measures must be taken to mitigate the effects of
urbanization, the exact nature of these efforts continues to be the subject of much debate.

Much of the current literature written in English on the topic of green roofs promotes
them as powerful tools for dealing with many of the present and future environmental concerns
characteristic of urban centres. Unfortunately little critical analysis or scientific research has
been conducted in Canada and the U.S., let alone Vancouver, to either support or discourage the
widespread implementation of eco-roofs or green roofs in general. In order to understand the role
green roofs might play in Vancouver’s own search for a more sustainable community, it is
important to recognise the city and region’s unique characteristics. Under the context of
Vancouver’s biophysical and built environment, and the Greater Regional District that invariably
influences it, the following section intends to critically evaluate the potential impacts of eco-
roofs for Vancouver. This discussion aims not to discount or trivialize the importance of
incremental contributions to improving environmental conditions, but rather identify those areas
that would experience the greatest impacts, and thus identify the most appropriate application of
eco-roofs.

ECO-ROOFS AND THE BIOPHYSICAL ENVIRONMENT

Climate can be understood at four levels—climatic zones, regional climate, local climate
and microclimate (see page 37). Defined as broad, geographic bands, ‘climatic zones’ are
affected primarily by large bodies of water, landmass and distance from the equator. Most of
Canada falls into the ‘cool’ or ‘cool-temperate’ zones. Regional climate refers to the regional
variations within climatic zones including differences in annual temperatures, amounts of sunlight, snowfall, rainfall, wind, etc. Local climate involves an even smaller footprint, and can include the anthropogenically produced urban heat island effect (Peck et al. 1999, 21). The climate of the Vancouver region is classified as west coast maritime temperate, with cool, wet winters and warm, somewhat dry summers. If it were just a bit warmer it would be called mediterranean (Wynn and Oke 1992, 29). The region posse the mildest climate in Canada, making Vancouver the most temperate major urban centre in the country. Muted by the conservative thermal climate of the ocean, the mean yearly temperature in Vancouver is about 11°C, the average high 29°C and the average low 4°C (City of Vancouver). According to the City of Vancouver and Environment Canada it rains, on average, between 136-159 days of the year, resulting in 940-1170 mm (37-46 in) of precipitation; and despite Vancouver’s reputation as a perennially overcast city, it does enjoy some 1,919-2,161 hours (or 80-90 days) of sunshine each year. Snow is not common, occurring 5-13 days a year, and amounting to 8-55 cm (3-22 in) of snowfall.

Sheltered from the westerlies by Vancouver Island, strong winds are uncommon. In the winter, average daytime temperatures rarely drop below freezing, though occasionally in midwinter outbreaks of cold polar air spill over the mountains. Spring sees both pleasantly mild and bright conditions as well as persistent cloudy, drizzling weather. Summer and fall experience largely cloud-free skies and light winds. Proximity to cool ocean water confers a moderating influence that keeps daytime temperatures from reaching uncomfortably high levels, and nighttime temperatures on the cool side (Wynn and Oke 1992, 28).

As the climate of the earth and Canada continues to change as a result of human activity, warmer temperatures in British Columbia and the Yukon are expected to bring milder
winters and warmer summers. Storms, on the other hand, may become more intense, wetter, and windier. Changes in temperature, rainfall and snowfall produce a profound effect on water, vegetation and animals, growing seasons, and local and regional economies (Environment Canada 2000).

Mitigating Mesoclimates
Reducing the Urban Heat Island Effect

The earth’s climate has never been static. “In the 13th century global temperatures were relatively warm, but then cooled from 1400 AD to about 1900” (Taylor and Langlois 2000, 3). In the GVRD, temperature records from the Vancouver International Airport weather station indicate an increase of 1-1.5°C for minimum temperatures in all seasons since records began in 1937, however little or no change in the average maximum temperature over that period (Taylor and Langlois 2000, Appendix C). While research suggests that urbanization has contributed to the region’s general warming trend, as Eric Taylor, a regional climatologist for Environment Canada, Pacific and Yukon Region, notes, it is difficult to delineate between urban influences and global climate changes.

According to Dr. Tim Oke, one of the world’s leading experts on urban heat islands and a professor at the University of British Columbia, the meteorological conditions in the GVRD, an upper level inversion caused by a West Coast high-pressure system, traps heat and pollutants in the region. Even in the absence of urbanization, this weather phenomenon causes the region to experience increased temperatures—a natural heat island. While an urban heat island, caused by human activity, does exist in Vancouver, Dr. Oke asserts that the region does not suffer from severe heat stress. In fact, he suggests that the region’s urban heat effect has actually brought more positive than negative changes, including warmer winters (Oke 2000).
As for the potential effects of eco-roofs on Vancouver’s urban heat island, Dr. Oke feels that, even though, every modification to the landscape contributes to meso scale conditions, air quality, and ozone, the widespread use of green roofs in Vancouver and the GVRD would not significantly improve the area’s urban heat island issues. Contrary to claims made by green roof proponents, Dr. Oke argues that it is not the evapo-transpiration of plants that provides the majority of the cooling benefits but rather the shade created by them (Oke 2000). Following this argument, while eco-roofs can prevent solar radiation from striking and heating the roof’s surface, they would not significantly cool the surrounding air. Eco-roofs, therefore indirectly impact the urban heat island effect, as surface shaded vegetation stays cooler, reducing the need for artificial cooling in buildings, itself a contributor to urban heat island issues. Unlike cities such as Chicago and Toronto, which suffer long hot summers, the Vancouver region experiences uncomfortably high temperatures at most only several weeks each year.

**Improving Air Quality**

Although Vancouver’s ambient (outdoor) air quality meets most standards and guidelines, the area also experiences the same ozone pollution found in many large, mid-latitude coastal cities. While the population and the amount of industrialization found in cities like Los Angeles, Athens, and Tokyo, far exceeds Vancouver’s, the region’s unique combination of meteorology, topography, and emissions considerably exacerbates its air quality problem (Wynn and Oke 1992, 268).

In 1990, Greater Vancouver pumped more than 600,000 tonnes of pollutants into the air, the majority of which came from motor vehicles (GVRD). While some pollutant concentrations have steadily decreased over the past 10 years—sulphur dioxide and nitrogen dioxide—others have continued to increase—ozone and fine particulates. Experts speculate that if significant
technological advances, behavioural changes and land use policies are achieved, Vancouver could see a continued improvement trend beyond the next decade (City of Vancouver).

Promotional, as well as informational, literature on the benefits of green roofs invariably mentions two things regarding air quality. The first is that 150 square metres of leaf surface area (approximately 1.5 square metres of uncut grass) supplies enough oxygen, through photosynthesis, to supply one person’s requirement for an entire year (Peck et al. 1999, 25). The second describes the ability of vegetation (and therefore green roofs) to filter the air. While research supports both of these assertions, it is important to consider two things: (1) conditions that might prevent or limit the performance of eco-roofs, and (2) the source of Vancouver's air pollution.

As discussed under *Potential Impacts and Issues*, plants only produce oxygen during the day, and even this can be dramatically reduced or altogether interrupted during periods of dormancy (in the winter for most of Canada, or during periods of drought). The amount of oxygen they contribute is therefore rather inconsistent.

Inconsistency also compromises eco-roofs’ ability to filter particulates from the air. The roof’s cleansing power relies on the type of plants used; certain species, particularly those with broad leafs, prove more effective in removing air borne pollutants than others. This leads to roofs with widely varying cleansing abilities. These arguments aside, for the already plant rich GVRD it seems more prudent to look at the source of air pollution.

The *1998 Emission Inventory for the Lower Fraser Valley Air Shed*, which included the GVRD, reported that vehicles, primarily light-duty cars and trucks, contributed 95 percent of the carbon emissions, and 39 percent of the total greenhouse gases in the region in 1998. If the number of vehicles continues to climb, as it has over the past 10 years, a 23 percent increase
since January 1991, even a city blanketed in eco-roofs would be challenged to maintain desirable air quality.¹

Brenda and Robert Vale illustrate the issue in their book *Green Architecture: Design for a Energy-Conscious Future* by pointing out that "the quantity of carbon dioxide released by a typical car travelling ten thousand miles a year on journeys to work and shop will need some two hundred trees to absorb it. A million trees will therefore cope with the carbon dioxide emission from five thousand cars. However visually it may appear, the city of a million trees organized around car travel can only be considered a ‘green’ city if its population does not exceed about twenty thousand (estimating one car to every four inhabitants)” (174). Vehicular emissions coupled with space heating, the second highest contributor to carbon emissions and greenhouse gases (from a single source), clearly illustrate the need for mitigation aimed at the source of pollution rather than just the resulting conditions.'

**Protection of the Roof**

Despite its reputation for overcast skies, according to *Canadian Climate Normals 1961-1990*, Vancouver receives nearly as many hours of sunshine as Toronto: 1,919 (80 days) and 2,038 (85 days) respectively (Environment Canada 1996). However, unlike many other areas of the country Vancouver experiences frequent temperature fluctuations. While much of Canada is characterized by sustained periods of freezing during the winter and/or long, hot summers, Vancouver’s temperatures can vary considerable during a single 24-hour period. During the summer, temperatures might fluctuate between 26°C during the day and 10°C at night. Particularly problematic for roofing membranes are the sways between just above and just below

¹ The percentage of increase was calculated using figures provided by the GVRD: vehicle ownership in January 1991, 1,000,362; and vehicle ownership as of August 2000, 1,233,651.
freezing (freeze-thaw cycle) during the winter. Tim Altizer of the Roofing Contractors Association of British Columbia (RCABC) feels that these less severe but more frequent winter temperature variations compromise membrane performance and longevity more than sustained periods at extreme low temperatures (Altizer 2000).

Compared to most conventional systems, eco-roofs provide significantly better protection against UV exposure and other external environmental influences (wind, hail, etc.), that contribute to roof failure and/or compromise longevity. However, such protective attributes, are not limited to green roofs, protected roofing systems (PMR), alternately know as inverted roofing membrane assemblies (IRMA), also provide this protection, but at a price comparable to other conventional systems. While PMR’s do not contribute environmentally, as eco-roofs arguably do, when confined to an analysis of capital investment, maintenance requirements, roof longevity, and potential replacement costs, they prove more financially prudent in both the short and long term.

It is important to note when evaluating the life of a roof that while the potential lifespan of buildings in North America, particularly commercial and industrial, may be around 50 years, they are often replaced long before this (Sulpher 2000). According to Stephen Sulpher, President of the Vancouver Regional Construction Association, it is not unusual for a property owner to remove a building from a site, due to lack of use, in order to save on taxes or build a more profitable development. Tim Altizer also points out that the property can simply end up exceeding the value of the building, making the empty lot far more valuable.

Providing Building Insulation

As discussed in Potential Impacts and Issues, despite assertions made by green roof proponents and manufacturers, the insulating abilities of eco-roofs prove rather negligible.
Similar conclusions can be drawn for sound insulation, as the thin profile of eco-roofs negates much of the substrate’s ability to mitigate routine disturbances such as aircraft, traffic and street noise.

As related to energy savings, “research in building physics show that there is almost no savings with light vegetation roofs, but with grass roofs (having a proper substrate thickness) and garden roofs, it is possible to save on energy. The amount of savings, however, is not enough to recover the cost of green roof construction within a reasonable period of time” (Hendricks 1994, 24). While the turf and sod roofs of medieval Scandinavia may have provided superior insulative qualities in relation to the other materials available at the time, compared to modern construction materials they are quite inadequate.

Vancouver’s mild climate negates the cost-effectiveness of using eco-roofs to buffer against external environmental conditions. While eco-roofs can prevent sunlight from striking the roof and warming the building during the summer, and reduce heat loss that results from wind blowing across the roof in the winter, the region’s relatively short summers (periods with high temperatures) and rather mild winters probably do not justify the initial cost of producing the roof, which is considerably more than that of other insulation methods and materials.

**Increasing Biodiversity**

The human impact on the natural flora and fauna of the Fraser Delta and associated flood plains has been both rapid and irreversible. By 1976, 70 percent of the original salt marsh and 30 percent of the original tidal marsh had been dyked, essentially destroying them. The pollution of Fraser sediments by heavy materials, human wastes and chemicals have had a devastating effect
on marsh plants. A 1976 GVRD survey of the remaining natural vegetation within its jurisdiction found a 24 percent reduction of these plants over a 16-year period.

With the expansion of Greater Vancouver, the majority of the native vegetation, and with it the habitats for much of the region's indigenous wildlife, have been removed from the city. The Douglas fir forest and western hemlock that once covered the area prior to 1880 has been dramatically reduced. Development pushed most of the large mammals, such as the bear and cougar out of Vancouver long ago, and the essential habitat of many of the smaller species—birds, fish, insects—has seriously diminished or been eliminated. The False Creek area alone once supported an amazing diversity and abundance of wildlife, including deer, elk, beaver, muskrat, geese, wildfowl, salmon, trout, perch, flounder, and sturgeon. Nelson Gray, coordinator for the Songbird Challenge, notes that approximately 37 of the 68 songbird species that reside or migrate through the region are in decline (Gray 2000).

Urbanization has also dramatically affected the habitats of salmon and trout, which were once found in more than 18 streams within the city. At one time, during the salmon run, English Bay would be so full of fish that it looked like one could cross to the south shore by stepping from fish to fish (Wynn and Oke 1992, 157-158). Despite urban impacts, though, the Fraser River Basin continues to produce more salmon than any other river system in the world. “Five species of salmon and 80 other species of fish, as well as 79 species of birds, rely on the Lower Fraser and its estuary for their critical habitats and migratory routes” (Nantel 1996).

Certain native species have found a niche in the urban ecosystem, and some have even prospered. The mouse, rat, and herring gull, and even some relatively large species such as the raccoon and coyote have managed to survive city life. A plethora of immigrant flora and fauna also maintain residence in the city: the prolific European starling, the grey squirrel, and the
pigeon to name just a few. An extremely varied pattern of eco-systems has emerged in Vancouver. While a few unmodified systems exist, the majority of them have been created. These include the practically “vegetative ‘desert’” of the commercial core, managed parks with homogeneous cultures of grass, and the varied flora of suburban neighbourhood gardens. Generally speaking, largely built-up areas have few species but large populations of them. Starlings, sparrows, gulls, rats and mice live off a range of foodstuffs found in waste and warehouse spillage. Neighbourhood gardens, on the other hand, house a greater diversity of species, as the range of habitats and their respective native and exotic species, are richer (Wynn and Oke 1992, 159).

The irreversible harm urbanization has inflicted on the Greater Vancouver Region’s once rich indigenous flora and fauna is irrefutable and tragic. Unfortunately, the displaced nature of roofs coupled with the limited ability of eco-roofs to sustain a wide variety of vegetation compromises their ability to support most of the species at risk. While more intensive green roofs might be tailored to meet the habitat requirements of some threatened bird species, eco-roofs would likely only provide direct benefits for select flying insects, and birds already established and flourishing in the region—sparrows, robins, starlings, crows, and the like.

Indirectly, however, eco-roofs could play an important role in helping to re-establish the regional hydrology, including the stream and watershed integrity aquatic species rely on for survival. “The Fraser River produces 66 per cent of all B.C. sockeye caught, 60 per cent of the total B.C. catch of pink salmon, 16 per cent of the Chinook, 11 per cent of the Coho, and 8 per cent of the chum. The annual economic value of the combined commercial, native, and recreational salmon fisheries on the Fraser River is over $300 million” (Nantel 1996). Discussed in more detail in the section to follow, urbanization radically alters the natural hydrological
system, which "in sum produces a very different habitat structure than the one in which aquatic organisms have evolved, usually resulting in decline or complete loss of at least some populations and substantial modification of biological communities" (Honer, et al. 2). The aquatic communities most directly affected by urbanized stormwater volumes are the smaller streams, which provide critical spawning and rearing areas for native salmonids. By mitigating stormwater runoff, eco-roofs help re-establish the natural water cycle and ultimately aquatic habitats.

ECO-ROOFS AND THE BUILT ENVIRONMENT

There are two major land-use classes according to a 1996 report by the GVRD: a green zone area (non-urban) and a developed area (Appendix II and III). The GVRD further divides the developed area into urban and vacant urban land, the former including housing, commercial, industrial, institutional, and transportation land uses (figure 6.1). While the name "green zone" suggests open space and parks, a wide variety of land uses fall under this category including: open space; parks and recreation; protected regional

<table>
<thead>
<tr>
<th>LAND USE IN GREATER VANCOUVER, 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAND USE</td>
</tr>
<tr>
<td>Urban</td>
</tr>
<tr>
<td>Vacant Urban</td>
</tr>
<tr>
<td>Non-Urban</td>
</tr>
<tr>
<td>Agriculture</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>% of all urban land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Land Use</td>
</tr>
<tr>
<td>Area (ha.)</td>
</tr>
<tr>
<td>Single Family Residential/Duplex</td>
</tr>
<tr>
<td>Townhouses and Low-rise Apartments</td>
</tr>
<tr>
<td>High-rise Apartments</td>
</tr>
<tr>
<td>Commercial</td>
</tr>
<tr>
<td>Industrial</td>
</tr>
<tr>
<td>Institutional</td>
</tr>
<tr>
<td>Transportation, Communication, Utilities</td>
</tr>
</tbody>
</table>

Source:
Greater Vancouver's Land Use: 1979-1996 Report
GVRD Strategic Planning Department

6.1 Land Use in the GVRD (GVRD).
watersheds; agriculture; and extractive industrial (e.g. mining). Although, the GVRD possesses an exceptionally high proportion of protected areas, parks, and open spaces compared to other metropolitan regions around the world, these types of land use are unevenly distributed within the region. Nearly 60 percent of the North Coast Mountains have protected status, whereas only 2.45 percent of the Fraser Lowland is conserved or parkland (recreational or open space) (Wynn and Oke 1992, 286).

In Vancouver, close to 90 percent of its approximately 113 square kilometres fall under what the GVRD qualifies as developed (Vancouver uses a slightly different system of categorization.) Single-family residential housing and streets et al. each respectively cover 32 percent of the urban area; followed by industrial, 8 percent; multi-family housing, 6 percent; commercial, 4 percent; and social/public service, cultural/recreational, and schools each at 2 percent (figure 6.2).

<table>
<thead>
<tr>
<th>Land Use in Vancouver</th>
<th>Acres</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Family</td>
<td>9,236</td>
<td>32%</td>
</tr>
<tr>
<td>Single Family</td>
<td>7,346</td>
<td>25%</td>
</tr>
<tr>
<td>Single Family + Suite</td>
<td>1,390</td>
<td>7%</td>
</tr>
<tr>
<td>Multi-Family</td>
<td>1,051</td>
<td>6%</td>
</tr>
<tr>
<td>Duplex, Rowhouse</td>
<td>721</td>
<td>2%</td>
</tr>
<tr>
<td>Apartment</td>
<td>741</td>
<td>3%</td>
</tr>
<tr>
<td>Apartment + Commercial</td>
<td>188</td>
<td>1%</td>
</tr>
<tr>
<td>Commercial</td>
<td>1,228</td>
<td>4%</td>
</tr>
<tr>
<td>Parks or Public Service</td>
<td>5,233</td>
<td>18%</td>
</tr>
<tr>
<td>Social or Public Service</td>
<td>561</td>
<td>2%</td>
</tr>
<tr>
<td>School</td>
<td>683</td>
<td>2%</td>
</tr>
<tr>
<td>Cultural or Recreational</td>
<td>482</td>
<td>2%</td>
</tr>
<tr>
<td>Park or Other Open Space</td>
<td>2,806</td>
<td>10%</td>
</tr>
<tr>
<td>Golf Course</td>
<td>700</td>
<td>2%</td>
</tr>
<tr>
<td>Industrial</td>
<td>2,410</td>
<td>8%</td>
</tr>
<tr>
<td>Wholesale or Storage</td>
<td>681</td>
<td>2%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>399</td>
<td>1%</td>
</tr>
<tr>
<td>Transport, Communications, Utilities</td>
<td>764</td>
<td>3%</td>
</tr>
<tr>
<td>Vacant or under construction</td>
<td>547</td>
<td>2%</td>
</tr>
<tr>
<td>Streets, Lanes, Sidewalks</td>
<td>9,148</td>
<td>32%</td>
</tr>
<tr>
<td>Total</td>
<td>28,907</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: BC Assessment Field Card Data - 1996

6.2 Land use in the city of Vancouver (Nowlan 2000).

Aesthetic/Psychological Improvements

The intuitive assertion that most people prefer natural views to a vista of asphalt rarely elicits argument. In fact, both popular and scholarly literature suggests that naturalistic views not
only prove more aesthetically pleasing, but also provide psychological benefits. The mayor of Chicago's reaction to the rooftop meadows and gardens he saw in Germany, mentioned in an earlier chapter, exemplifies this emotional impact: While one does not wish to disregard aesthetic and psychological contributions, in light of the region's abundant natural and orchestrated scenery, an aesthetic argument for eco-roofs does appear less poignant. Not only does Greater Vancouver benefit from a spectacular natural setting, but it also encourages and funds a variety of beautification projects. These manmade sceneries include Vancouver's Green Streets Program, which promotes the planning and maintenance of street gardens, and the region's various "greenways" projects, such as bike paths, waterfront promenades, environmental demonstration trails, and heritage walks (City of Vancouver).

**Mitigating Stormwater**

Vancouver's first sewer systems were constructed in approximately 1890. Up until the 1940's, combined sewer systems, those that carry wastewater and stormwater in the same pipe, were the most economical and effective systems available. Significant replacement of Vancouver's sewer systems began in the 1960's, and throughout the 1970's variable levels of annual replacement, up to two percent, of the system occurred. Since 1981, as part of the Sewers Long-Range Plan, Vancouver replaces one percent of the system each year. Upgrading of older sewers generally occurs at the end of their useful lives, which is typically 80-100 years. In selecting sewers to be replaced, a number of factors are considered including the age, condition and capacity of the pipes, flooding risk reduction and pollution abatement benefits. All sewers replaced are upgraded to today's capacity standards. In conjunction with the program, the sewer infrastructure is being changed from the combined systems to separate systems, one for carrying...
wastewater—used water and sewage—to treatment plants, the other for diverting stormwater—runoff from rainfall—to the closest stream, river, lake or ocean (City of Vancouver). Today, combined sewer systems still service close to two-thirds of Vancouver, New Westminster, and a small portion of northwest Burnaby (McTaggart 2000).

Historically, the GVRD has used the collect and direct approach for stormwater (Neninger 2000). Stormwater is collected in stormwater or combined sewer system pipes and then directed to waste treatment plants or overflow destinations such as detention ponds. During heavy rainfall, the volume of stormwater runoff can become too large for combined sewers to handle. Under these conditions some of the mixed wastewater and stormwater overflows into the Vancouver Harbour or the Fraser River. In the GVRD, combined sewers overflow about 36 billion litres of mixed wastewater and stormwater every year. In Vancouver, New Westminster, and northwest Burnaby these spills go into Vancouver Harbour, the North Arm and Main Stem of the Fraser River about 140 times annually, and into both English Bay and False Creek about 45 times a year (GVRD, 1993).

The City of Vancouver has developed several initiatives in addition to the infrastructure reconstruction, to reduce and eliminate flooding and combined sewer overflows (CSOs). These include: regulation of sewer connections; a inflow and infiltration program, which looks to reduce the amount of extraneous stormwater entering sanitary sewers by diverting runoff to small nearby waterways; a Sump Exfiltration Pilot Program, which evaluates the effectiveness of decreasing storm runoff from properties through the use of exfiltrating sumps; a Rain Barrel Program that encourages the use of "Rain Barrels" to store rainwater for garden usage thus conserving domestic water and reducing rainfall runoff from properties; and a Roof Leader Disconnection Pilot Project, which encourages the disposal of roof leader runoff by infiltration in
areas of the City with adequate surface permeability (City of Vancouver). The city has also recently introduced more stringent impermeability controls; a new bylaw for all single-family residential zones (RS) limits the amount of impermeable materials, including building coverage, to 60 percent of the total site area. For buildings existing prior to the bylaw’s enactment date, or under special circumstances, up to 70 percent site coverage may be approved (Addis 2000). While Europeans have successfully marketed green roofs and their stormwater mitigating properties for years, it is only recently that the City of Vancouver and the Greater Vancouver Regional District have begun investigating the potential implications for this region.

**Improving Stormwater Quality**

Vancouver proudly possesses some of the purest tap water in the world. Water is collected from rainfall and snowfall in the Greater Vancouver Regional District’s Capilano and Seymour watersheds (City of Vancouver). While these protected watersheds and Vancouver’s gravity fed system allows the city to supply tap water with minimal treatment at a very low cost, waterways—streams, river, and other water bodies—at lower elevations have begun to suffer the impacts of urbanization.

“After 450 million years of assimilating natural liquid waste, the receiving environment of the delta that is now Greater Vancouver has within the past 60 years succumbed to elevated levels of contamination” (Nantel 1996). Numerous studies have documented the degradation of water quality as a result of urbanization (Hall et al. 1998, 111). The major sources of water pollution include point sources such as the effluent discharged from pulp mills, industrial plants and municipal sewage treatment facilities; variable-flow point sources such as combined sewer overflows; and non-point sources such as urban, industrial, and agricultural runoff.
Surface runoff coupled with the overflows from outdated and insufficient combined sewer systems (discussed in the next section) is quickly becoming a serious problem for the region (Gray and Tuominen 1998, 2). Winter rainfall entrains a wide range of suspended and dissolved substances as it runs off residential and industrial areas and into storm sewers. Unlike the wastewater that drains from households through the sewer system to treatment plants, much of the water that flows over impervious surfaces, such as sidewalks, driveways, streets, and roofs enters the storm sewer system where it is released untreated into the local waters. Any chemicals or hazardous products that are on these surfaces can be swept up by the stormwater and discharged to these water bodies. Urban stormwater runoff is a significant source of trace metals and hydrocarbons that come from vehicle use (Hall et al. 1998, 111). Hall et al. found that “the loading of contaminants in street runoff and the different reaches of the streams was directly related to traffic density and land cover permeability of the drainage area” (Hall et al., 1998, 4). CSO and surface pollution not only jeopardizes the health and natural habitats of numerous wildlife species but also the well being of the region’s human population; serious diseases such as hepatitis and meningitis, as well as milder conditions such as diarrhea, and skin and ear infections can result from exposure to sewage contaminated water.

Science has both demonstrated and utilized the ability of soil and vegetation to filter pollutants from water. The completely natural “Living Machine” sewage treatment system relies entirely on the cleansing properties of plants to transform raw sewage into drinking water. Wayne Belzer of the Aquatic and Atmospheric Division of Environment Canada notes that studies have found mosses and peat to be particularly efficient natural collectors of particulates and gases (Belzer 2000). Depending on the substrate composition and the type of vegetation, an eco-roof could filter out the fecal matter of birds or airborne particulates that have settled on the
roof or accumulated in the rainwater. They cannot, however prevent substances on the membrane itself from entering the runoff, as the membrane is the last surface water passes over before leaving the roof. While eco-roofs might help mitigate the above forms of contamination, it could also compromise roof runoff, in much the same way gardening at grade can, if in chemical fertilizers and/or pesticides are used.

The overwhelming majority of stormwater pollution occurs as a result of vehicular pollution (i.e. the hydrocarbon slick on the roadways from exhaust), and from contaminants spilt at grade (oil, chemicals, etc.). In a case of study of the Brunette watershed area, located in Burnaby, Hall found that changes in the area of major land uses and impermeable ground cover had been relatively small over the past twenty years and therefore “not likely responsible for the large changes observed in sediment trace metals levels” (Hall et al. 1998, 114). Vehicular traffic density, on the other hand, had increased by more than 44 percent indicating a direct relationship to changes in contaminant levels in urban streams. Given that both vehicle pollutants and contaminants at grade will increase in proportion to increasing population and urbanization, efforts should be focused on attending to these non-point sources and their causes (McGreer and Belzer 1998, 20).

**Mitigating Stormwater Volumes**

The mitigation of urban stormwater runoff represents, by far, the most influential potential impact of eco-roofs in the GVRD. The root cause of stormwater problems lies in the development of impervious surfaces which generally consist of roads, sidewalks, parking lots, driveways, patios, and rooftops, but can also include areas of highly compacted soil and some playing fields (GVRD 1999, 7). As these surfaces increase, the hydrograph is altered as higher
Hydrological Changes Associated with Increased Impervious Surfaces

6.3 Hydrological changes associated with increased impervious surfaces according to the City of Olympia’s Impervious Surface Reduction Study (City of Olympia, Public Works Department 1996).
peak flows occur much earlier in a rainfall event (Hall et al. 1998, 110). This results in numerous and extensive changes in the region’s hydrology and water quality (figure 6.3). The two hydrological processes impacted by these changes are retention and detention. Retention “includes both long-term surface and sub-surface storage and loss back to the atmosphere, surface evaporation and evapo-transpiration through vegetation. Loss of retention capacity is closely related to loss of vegetation and changes to the type of land cover” (Chilibeck 1995, 3). “Detention occurs naturally through the complicated surface and subsurface flow paths taken by precipitation and surface runoff. Loss of detention is attributable to the construction of storm drainage systems and development of impervious areas such as pavement and roofs” (Chilibeck 1995, 3). This results in the reduction or removal of the natural sinks for water, sediments, and pollutants in the aquatic ecosystem.

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>% TIA Conversion Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unclassified</td>
<td>0</td>
</tr>
<tr>
<td>Agricultural</td>
<td>5</td>
</tr>
<tr>
<td>Residential Single Family</td>
<td>40</td>
</tr>
<tr>
<td>Rural Residential</td>
<td>10</td>
</tr>
<tr>
<td>Townhouse</td>
<td>80</td>
</tr>
<tr>
<td>Multi-family</td>
<td>90</td>
</tr>
<tr>
<td>Commercial</td>
<td>90</td>
</tr>
<tr>
<td>Industrial</td>
<td>75</td>
</tr>
<tr>
<td>Institutional</td>
<td>90</td>
</tr>
<tr>
<td>Transport</td>
<td>90</td>
</tr>
<tr>
<td>Park/Open Space</td>
<td>1</td>
</tr>
<tr>
<td>Open Water</td>
<td>0</td>
</tr>
<tr>
<td>Undeveloped</td>
<td>1</td>
</tr>
</tbody>
</table>

These conversion percentages reflect the latest estimates used by the GVS&DD (June 1999). They differ slightly from the conversion factors reported and used in the Proposed Watershed Classification System for Stormwater Management in the GVS &DD Area. The test watersheds from that report were re-assessed using the above percentages and the updated results are reflected in this report.


In order to approximate the percentage of impervious surface area in the GVRD, researchers assigned typical percentages of total impervious area (%TIA) to the different land use classes. For example, in the GVRD a single-family residential site has a %TIA Conversion Factor of 40, while multi-family and commercial zones sites carry a 90 (figure 6.4). According to the Greater Vancouver Sewage and Drainage District, a large portion of the city of
Vancouver has a more than 40% TIA. If development continues status quo and mitigating actions not taken, this portion is only expected to grow (See Appendix IV and V) (Regional Utility Planning Group, 1999).

Emerging trends in urban flow management have recognized the importance of on-site stormwater mitigation. Eco-roofs can provide varying amounts of retention, depending on the season, by absorbing and utilizing a portion of the water that falls on them. However, during the winter, when stormwater volumes are greatest and such retention is negligible, it is the roof’s ability to detain rainfall and slow runoff from the roof during and immediately following a storm event that proves invaluable. Unlike residential zones, where significant amounts of pervious surfaces—landscaping, lawns, and gravel—at grade help moderate stormwater from the roof and other hard surfaces, for the large quantity of highly impervious commercial and industrial areas, eco-roofs may represent one of the few ways to reduce peak stormwater runoff volumes at the site level.

Industrial and commercial land use constitutes close to 19 percent of the GVRD urban land area. Both commercial and industrial zones allow up to 100 percent impervious coverage, and the structure(s) itself can cover a majority of the site. This is particularly characteristic of commercial/mixed use development (C-2, C-2B, C-2C, C-2C1) and some light industrial zones (Mount Pleasant Industrial Area (I-1), Brewery Creek Area (IC-2)) where densification is often maximized (French 2000). Given the high degree of imperviousness in these zones, it can be assumed that nearly 100 percent of the rainwater that falls on this portion of the GVRD enters the stormwater system during storm events. The often expansive, low-slope roofs in these zones—commercial buildings generate roughly 10,000 ft² (i.e. office building) to 150,000 ft² of roof area (i.e. shopping mall), and moderate to large industrial projects average 50,000 to
100,000 ft² of roof space—if covered with green systems could significantly reduce and delay this runoff (Altizer 2000).

A number of variables affect the amount of water a green roof can absorb: substrate depth, composition and saturation; type and quantity of vegetation; ambient air temperatures; relative humidity; as well as the intensity and duration of the rainfall event. The 13 cm (5 in) Soprema system on Mountain Equipment Co-op’s eco-roof in Toronto can reportedly retain its dry weight (20 psf) or up to two-thirds of its volume in water. This translates to a maximum retention of just over 8 cm (3 in) of rainfall at any one time.² (Given that, in the interest of plant health, the roof is slightly moist at all times, actual maximum rainfall capture is likely somewhat lower). Once the roof achieves saturation, additional rainfall percolates down through the layers and off the roof for several hours or even days following the storm event. In the south eastern municipality of Surrey, which receives moderate amounts of rainfall for the GVRD (Vancouver

6.5 Analysis of stormwater events over 33 years for Surrey, British Columbia. Rainfall Data Source: Kwantlen Park Raingauge Data from Jan 1, 1962 - May 1, 1995 (Condon).

² This system uses a specially formulated “soil” designed to maximize water retention.
receiving less, and the North Shore experiencing considerably more) approximately 70 percent of the rain events drop less than 0.5 in (1.3 cm) of water, 21 percent drop between 0.5 and 1 in, and only 9 percent result in over 1 in (more than 2.54 cm) (and often not significantly so) (figure 6.5) (Condon). Even if the above system captured only one-third or one-sixth of its volume (4 cm (1.5 in) and 2 cm (0.8 in), respectively, of rainfall) this would still provide adequate retention for managing most of the region’s stormwater events.

An eco-roof used in conjunction with infiltration measures at grade, such as pervious pavement, produces a synergistic effect as the roof retains a percentage of the water until the infiltration systems are able to deal with it. In many respects the relationship emulates the forest floor. The layers of the roof behave like duff (pine needles and fallen leaves), holding water until the roots of the forest vegetation (the roofs own plants) can take it up or it migrates into the soil (infiltration surfaces at grade). By increasing the chances for stormwater runoff to enter the natural system at grade, eco-roofs help restore the natural hydrological processes in a region, and ultimately the aquatic species that depend on it.

High-density areas serviced by combined sewer systems or particularly large catchment areas, such as the Clark Drive district, which suffers the most CSO problems in the region, would experience considerable benefits from eco-roof implementation. Buildings (and therefore the roofs) in high-density areas generally cover close to 100 percent of the site (parking usually delegated to street side or underground lots). By utilizing eco-roofs, nearly all the rainfall on the sites’ would be either captured on the roof and/or slowly drained off the roof, substantially reducing the load on an area’s storm runoff system. According to Steve McTaggart, an assistant sewers engineer for the City of Vancouver, in large catchment zones, parts of the region where combined sewer systems service a large, continuous area, even moderate reductions in
stormwater runoff could help offset combined sewer overflows. In highly urbanized areas with limited space, eco-roof implementation could act as a substitute for the retention ponds used in areas of lower density. Their installation would likely occur when sites are redeveloped, and in fact, could be a stipulation for future projects.

The feasibility of eco-roofs for stormwater mitigation in those areas serviced by separate sewer systems proves more difficult to ascertain. Eco-roofs could help reduce current loads in already built-up areas and work as a preventative measure in prospective developments. If infiltration devices are used at grade, the benefits improve considerably. When residents of the region face liquid-waste disposal fees that reflect the amount of stormwater that leaves their sites, such as those already used in Eugene, Oregon and throughout Europe, and/or local governments initiate policies and regulations requiring stormwater mitigation on-site, there will be increased incentives, financially and otherwise, for eco-roof implementation.

CONCLUSION

Society faces a dizzying array of environmental, social, cultural, political and economical conundrums. They coexist, intertwine and create the intricately complex and often delicate fabric of society. In the Greater Vancouver Regional District, while some environmental problems still seem somewhat far removed, others are already haunting its waterways, its air quality, and its biological diversity. Researchers, professionals, and laymen alike want answers, need answers, to these ills and those that lie just on and over the horizon. For the past three decades, people worldwide have been working to define the sustainable and environmentally responsive development and design needed to maintain the functional integrity of the ecosphere the world’s population calls home. While sustainability remains difficult to describe in substantive terms, its implications for building design are relatively clear; it requires
"transforming existing buildings and building new ones to function, both individually and collectively, in concert with natural systems" (Cole 1995, 3). This transformation, however, represents a complex and often controversial subject, covering such issues as availability of technology and information, and economic and legal requirements.

Practitioners face a number of difficult questions, and often find themselves tainted by intuitive reasoning and emotional inclinations. Society's reluctance to tackle the actual sources of today's urban ills haunts many governments' policies and actions. Whether it is out of an unwillingness to forgo their current lifestyle or a faith in the power of technology, people continually seek a comfortable panacea to their problems. Despite the glowing assessments of green roofs in popular literature, as well as informational publications, they represent but a small, albeit important, piece in the larger complex puzzle of sustainable development.

The success and widespread implementation of green roofs across Europe stems from regulations and policies enacted in response to environmental degradation foreign to much of North America. Germany, the leading researcher and implementer of extensive green roofs, houses a population of over 80 million people in an area one-third the size of British Columbia. The ramifications of such densities and urbanization, not only in Germany but much of western Europe, has forced many countries to implement, what would be considered in North America, prohibitively expensive practices and regulations. European research clearly supports the ability of green roofs to cleanse the air, mitigate meso and microclimates, protect the roof, and moderate stormwater volumes. How these abilities might contribute to the health and welfare of Greater Vancouver, as well as aid its slow transition to sustainable design and development was the investigation undertaken by this thesis.
The Vancouver region's unique and in many respects privileged landscape and environment continues to provide its residents and visitors with remarkably clean and healthy living conditions despite the pressures of urbanization. Its environmental degradation is still arguably at a stage where it can be addressed with a broad range of low to moderately priced preventive and corrective measures. The difficulty lies in identifying the appropriate means for addressing each perspective issue. Although the reported benefits of green roofs are numerous, in Vancouver and its region their greatest impact, and consequently financial feasibility, resides in the mitigation of stormwater. Storm runoff, and issues related to it, constitutes a persistent and growing problem in the GVRD, one that monopolizes, both directly and indirectly, much of the time, research, and efforts of local, provincial and federal organizations. The ability of an eco-roof's even thin profile to mitigate this pressing issue could result in widespread, and even unforeseen, positive ramifications.

The successful implementation of green roofing technology in North America will require extensive and detailed, North American-based, scientific research including field tests. While unavailable to this investigation, a number of studies recently started by both manufacturers of green roofs and independent research organizations promise much needed statistical data for the emerging North American green roofing industry. In the Vancouver region, increasing interest by both municipal governments and the GVRD, in rooftop landscapes and their potential for stormwater mitigation and urban agriculture, support the prospects for future local and regional research.

Volumes of impressive statistical data, however, do not create change; people committed to, or required to, making a difference create change. Regardless of how and to what degree green roofs might contribute to Vancouver and the region's environmental health and long-term
sustainability, the realization of green roof potential ultimately resides in making fundamental changes to planning and development practices and policies. While the Greenbacks report cites several barriers to green roof utilization—lack of knowledge and awareness; lack of incentives to implement; cost-based barriers; and technical issues and risks associate with uncertainty—comparisons between North America and Europe suggest that it is legislated regulations, which demand attention and compliance, that are vital to the exploration and implementation of sustainable practices such as green roof technology. Supported by rigorous research and incorporated into long-range planning policies and objectives, eco-roofs represent a valuable instrument for addressing some of the implications of urbanization and Vancouver’s gradual transition to a sustainable city of the future.
APPENDICES

I. Greater Vancouver Regional District (GVRD).

II. Greater Vancouver Land Use, 1996 (GVRD).

III. Greater Vancouver Green Zone, 1996 (GVRD).

IV. Percent Total Impervious Area in 1996 as an Indicator of Potential Stormwater Impacts and Biological Communities (Regional Utility Planning Group 1999).

V. Forecast Percent Total Impervious Area in 2036 as an Indicator of Potential Stormwater Impacts and Biological Communities (Regional Utility Planning Group 1999).
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Greater Vancouver Regional District
APPENDIX II

Greater Vancouver Land Use, 1996
APPENDIX III

Greater Vancouver Green Zone, 1996
APPENDIX IV

Percent Total Impervious Area in 1996 as an Indicator of Potential Stormwater Impacts and Biological Communities
APPENDIX V

Forecast Percent Total Impervious Area in 2036 as an Indicator of Potential Stormwater Impacts and Biological Communities
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