RETHINKING THE URBAN EPIDERMIS:

A study of the viability of extensive green roof systems in the Manitoba Capital with an emphasis on regional case studies and stormwater management.

By

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A Thesis Submitted to the Faculty of Graduate Studies for Partial Fulfillment of the Requirements of the Degree of

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RETHINKING THE URBAN EPIDERMIS: A STUDY OF THE VIABILITY OF EXTENSIVE GREEN ROOF SYSTEMS IN THE MANITOBA CAPITAL WITH AN EMPHASIS ON REGIONAL CASE STUDIES AND STORMWATER MANAGEMENT.

BY

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

of

MASTER OF LANDSCAPE ARCHITECTURE

Abstract

Living roof systems, also known as green roofs, are increasingly common in many European cities. This ecologically based construction technology has yet to be widely adopted within Canada. Chapter One of this thesis introduces the scope of the research herein. Chapter Two consists of a literature review of issues of theory and practice pertaining to extensive green roofing. The interrelationships and prevailing attitudes behind notions of design, ecology, and sustainability are discussed and Rooftop typologies and the history of rooftop gardens are discussed. Extensive green roofs are defined and differentiated from intensive green roofs. The second chapter describes the most recent techniques employed in the construction of extensive green roofs, discusses the costs and benefits associated with these systems and explores the relationship between green roof infrastructure and stormwater management. Chapter Three reports on a survey that was distributed to building owners and operators of facilities located in Minnesota and Manitoba that have employed extensive green roofing. The case analysis explores the performance of existing green roof systems with respect to their ability to function within cold climates, their ability to retain stormwater, the relationship of the roofs with their natural environment, the public perception of the roofs, the cost savings or losses associated with the roofs, and the owner/operators overall impression of their green roof. Chapter Four discusses the selection criteria and analysis of a study site and provides spatial data for the analytical study of the widespread use of green roofs undertaken. Chapter Five utilizes the selected study site to assess the potential benefits of extensive green roofing as a viable non-structural stormwater management technique. The study identifies measurable changes in the amount of stormwater runoff discharged into the surrounding watershed assuming the widespread use of extensive green roofing. Potential savings in sub-grade infrastructure costs realized through the use of green roof systems are identified. A comparative cost analysis between extensive green roofing, sub-grade-stormwater storage tanks, and stormwater retention ponds is then completed. Conclusions as a they pertain to the research questions asked are made and recommendations for further research and concludes with an exploration into the policy issues surrounding the use of green roofs and makes suggestions for further research.

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This work could not have been completed without the guidance of committee members; Professor Charlie Thomsen, Dr. David Van Vliet and Mr. Derek Murray. I am sincerely grateful for the enthusiasm and expertise that you brought to this project.

To my mom and dad, I thank you for your patience, love and support. Your tireless and unconditional generosities were a greater help than you could ever imagine. To family members and friends who have encouraged and inspired me, I thank you.

To my wife, Amanda, you have given me the confidence and fortitude to pursue my convictions, you have taught me how to realize my dreams and aspirations. I dedicate this text to you.

"What is demanded is a change in our imaginative picture of the world."

- Bertrand Russell

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Chapter One – Thesis Structure

1.1 Introduction

Rooftop surfaces play a significant role in the ecological functioning of all urban environments. To date, this ecological importance has been largely ignored. Often, architects design rooftops with the singular purpose of providing shelter. Similarly, landscape architects often neglect rooftop surfaces by focus their expertise on the area surrounding the built form or the green space enclosed within the structure. The potential for the rooftop to act as a synthesis between nature and shelter is subsequently ignored. In any given city, rooftops comprise thousands of acres of barren space. Not only could this vast and empty expanse be used to mitigate innumerable ecological problems, it could also be used to transform the visual and spatial quality of our urban, commercial and industrial landscapes.

Over the past century, architecture that bears little relation to the ecological processes of its surroundings has dominated our urban landscape. Recognizing and accepting that, "nature is a ubiquitous whole that embraces the city" (Spirn, 1984, p. 5) has powerful implications with respect to how we design and alter the physical environment. Human beings dwell in relation to nature, not merely within nature. We inhabit the surplus of the earth rather than the earth itself. In seeing ourselves as dwelling within the residual of our planet's productive capabilities, we have failed to recognize the network of relationships that we belong to. "As such, human dwelling is always an estranged construction, one that can be as destructive and parasitic as it can be reciprocal and symbiotic" (Corner, 1997, p.96).

There exist two distinct types of green roof systems, intensive and extensive. As accessible spaces, intensive green roofs are essentially outdoor rooms. These systems are installed on flat roofs and generally consist of vegetation in containers or raised beds separated by pathways of decking. Weight and the carrying capacity of the roof structure are important factors to consider when designing an accessible green roof. Installation and maintenance costs of intensive systems are high (Johnson & Newton, 1991).

"Extensive" green roofs, the focus of this thesis, are roofs on which the planted material acts as additional layer of roofing material. These roofs are not usually designed to be walked upon. As a result, they are not required to meet the same building standards as roofs constructed for regular access (Thompson, 1998). Extensive living roofs typically cover the entire roof area of a building with a thin growing medium. This growing medium can support low vegetation such as moss, sedum, herbaceous plants and a variety of native grass species. These roofs are not new, they are a modern version of a centuries-old tradition in Scandinavia (Thompson, 1998). In order to achieve a stable system that requires minimum maintenance, the proper choice of vegetation, substrate mix and substrate thickness, must be determined (Grozeva, 1997). Climate, with an emphasis on precipitation, is the most significant factor in determining a self-sustaining balance (Grozeva, 1997).

Within the regional context of the Manitoba Capital Region, no research has been undertaken in order to determine the potential benefits of employing green roof technology as a means to mitigate the various exigencies associated with stormwater runoff. Osmundson (1999) notes that the predominant North American experience has been to look at the aesthetic qualities of [intensive] green roofs. Though the importance of intensive green roofing strategies must not be overlooked, we would do well to delve further into an exploration of the European experience where the widespread use of extensive green roofs has occurred primarily as a corrective measure used to improve environmental health within dense urban settlements. Considering the lack of hard evidence regarding the design, construction and performance of green roofs within North America, there is little reason to speculate over the reluctance of designers to specify the use of extensive green roofing in their projects. The risk associated with the uncertainty of the performance of green roofs is a significant hurdle to overcome (Peck, 1999).

Illustration 1.1 Darmstadt, Germany - Housing complex

(David Van Vliet)

1.2 Research Problem

Green roofs are currently used in regions of Europe that have similar climatic conditions to the Manitoba Capital Region. This suggests that extensive green roofs could be a viable and ecologically sustainable roofing alternative suited to the local climatic conditions of the Manitoba Capital Region.

The research problem explored in this document is twofold.

1. Emphasizing cold climate performance, are there any local examples or cases within close proximity to the Manitoba Capital Region that could indicate the potential merits and/or shortcomings of green roof systems within the context of this region?

2. To what degree might extensive green roofs reduce stormwater runoff, decrease sub-grade infrastructure costs, and benefit the ecological health of a designated study site located within the City of Winnipeg?

Until very recently, the limited North American research on green roofs has focused primarily on design development and small-scale prototypes. By simulating the widespread use of green roofing in the selected study area, the present research will determine the broad-scale implications of green roof systems on reducing stormwater runoff. Doing so makes a logical step in uncovering the potential merits of using extensive green roofs over a large area. It is hoped that this study will be of interest to municipalities interested in finding alternative methods of managing stormwater.

1.3 Research Methods

Because the research question addressed within this thesis is twofold, several different research methods were employed. A brief description of these methods and their respective location within this document are discussed in the sub-sections below. A schematic diagram of the methods used in this study can be found in Figure 1.3.

1.3.1 Literature review – Chapter Two

In addition to investigating the contrasting notions of ecological design and sustainability, this research has explored the culture, history and ecology of the rooftop with specific reference to rooftop vegetation. The literature review includes the translation of two sources from German into English. The literature review is used to explain the physical design components of both conventional and flat roofs, and looks at four specific types of green roof plant mixes. The benefits and costs of green roofing are discussed. Lastly the role that green roofs play in the management of stormwater is outlined. Following the discussion at the end of this chapter recommendations for further research are made.

1.3.2 Participant survey and case study analysis – Chapter Three

A survey was created and sent out to owners and managers of green roofed buildings located within southern Manitoba and Minnesota. In total, nine buildings were surveyed and qualitative data regarding the following themes were collected:

- Green roof design
- Cold-climate performance of green roofing
- Watershed health and green roof stormwater retention
- Relationship of green roofing to the natural environment
- The public perception of green roofing
- Cost savings and losses attributable to green roofing

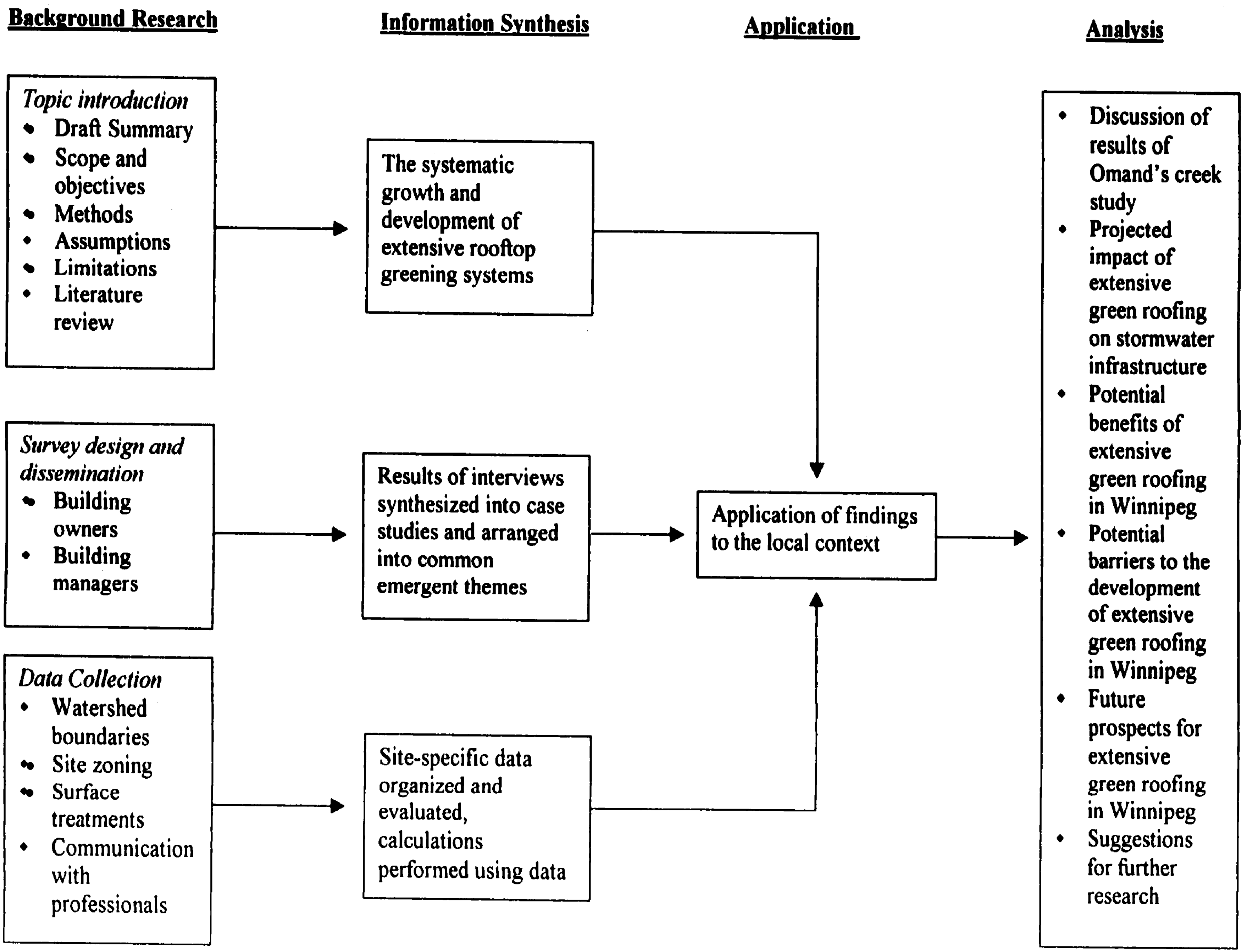
1.3.3 Site Analysis – Chapter Four

This chapter begins with a brief review of literature regarding the natural history of Manitoba, the impact of urbanization on site runoff, and the history and development of the study site (adjacent to Omand's Creek within the City of Winnipeg, Manitoba). Next, the site was analyzed at macro, meso and micro scales. At the macro scale, the analysis looked at the Natural history of the study site, the relationship between the natural history of the region and its impact on urban development, and the hydrologic implications of urbanization on the City of Winnipeg. At the meso scale, this analysis looked a the historical development of the watershed in which the site is located, the present day-limits of this watershed, the health of this watershed with an emphasis on the urban downstream reach, the ecology of the area, and commercial growth within the area. The micro-scale analysis breaks the site down into three zones and measures the respective areas of the various surface treatments found on the site.

1.3.4 Stormwater calculations – Chapter Five

The stormwater calculations used within this chapter are based on the Rational Method found in Munson (1974). Using the data collected in Chapter Four, assuming three different storm intensities, these calculations project the amount of runoff flowing from the site under current conditions, green roofed conditions, and pre-development conditions. The importance of regional rainfall and runoff data is crucial to these calculations.

Illustration 1.3 – Schematic diagram of research methods employed



The basic cost of providing sub-grade stormwater infrastructure to the study site is determined for each land-use scenario assuming a twenty-year rain event of one-hour duration. Any cost savings under each scenario are noted as a percentage and projected against the current annual spending by private and public sources on land drainage infrastructure. Thus, projected citywide annual savings accrued through the use of green roof infrastructure are determined.

Lastly, using data specific to the Manitoba Capital Region and a conservative estimate for the coefficient of runoff for extensive green roofing, the yearly cost per cubic foot of water retention using green roofs is calculated. This cost estimate is then compared to the yearly cost of retaining stormwater using sub-grade storage tanks and stormwater retention ponds under the most recently available estimates for construction (estimates do not include maintenance). Following the discussion at the end of this chapter recommendations for further research are made.

1.4 Research Objectives

The objective of this research is to provide the reader with a better understanding of the benefits and costs that could accrue through the widespread implementation of a green roof strategy within the City of Winnipeg. By understanding these benefits and costs, it is hoped that research geared toward the development of a living roof industry within the Manitoba Capital Region will be facilitated.

Upon exploring the wider theoretical context of ecological design, the literature review undertaken in Chapter Two identifies and analyzes previously documented studies regarding extensive green roof systems. The European experience with extensive green roofs is well recognized yet often not accessible due to language barriers. This chapter will impart information, some of which was previously unavailable to English language readers.

The intent of the participant survey undertaken in Chapter Three is to interpret the relative successes and failures of existing green roofed structures that have been built in regions that experience the same or similar climatic conditions as that of southern Manitoba. By generating data that are directly related to local conditions, the viability of using extensive green roofing within the local context can be better assessed.

Chapter Four of this document involves an analysis of the selected study site from both macro and meso-scales and the collection of site-specific data. Chapter Five explores the role that living roofs could play in reducing stormwater runoff from the selected study site. The objective of Chapter Five is to generate information that will help determine the relative ecological and economic effectiveness of extensive green roofing as a means of reducing stormwater runoff from urban developments situated within the Manitoba Capital Region.

1.5 Assumptions and Limitations

Current methods for measuring site runoff utilize numerical coefficients that reflect the relative ability of a given surface type to absorb precipitation. The greater the impermeability of a surface, the higher its runoff coefficient will be. Conversely, a surface that is readily able to absorb water will have a low runoff coefficient. The amount of moisture that is held inside of an absorbent surface radically alters its ability to absorb precipitation. The coefficient for runoff of a fully saturated absorbent surface will be higher than that of an unsaturated surface of the same material. The calculations made within Chapter Five of this study assume that the substrate of the green roof is free of moisture prior to the onset of precipitation. Because southern Manitoba experiences direct sunlight, frequent dry periods, strong summer winds, and periodic summer thundershowers ("Canadian Climate", 1998), this is not an unreasonable assumption. Measures used to compensate for this assumption are further discussed in Chapter Five.

The substrate depth and plant mix of a green roof suited to the prevailing climatic conditions of the Manitoba Capital Region has not yet been determined. In designing a green roof, the depth of the substrate and the type of plants used on the roof play a critical role in determining the amount of time that it takes for precipitation to saturate the roof. This design specification greatly influences the rate at which precipitation is subsequently shed from the roof. Because the coefficient for runoff of a typical extensive green situated in southern Manitoba has yet to be determined, the coefficient used for the purposes of this research is based on consultations with professionals in the field and German data.

In order to accommodate green roofing, this study notes that some of the buildings studied in Chapter Five may require structural reinforcement during their construction or retrofit. This study assumes that the buildings on the study site could be retrofitted in a cost-effective manner.

By simulating the widespread use of green roofs, this research document places an economic value on the potential savings to sub-grade infrastructure. However, this research does not attempt to assign an economic value to all of the services provided by green roofs (such as the creation of oxygen or the absorption of radiant heat energy). Methods appropriate to placing value on such services fall outside of predominant models of economic valuation. This research recognizes the inherent value of these services but does not attempt to place a dollar value on them.

This study will help to develop an awareness of an alternative means of construction that advocates a synthesis between nature and shelter. Because further (regionally specific) research is required, the design of a system suited to the specific climatic requirements of the Manitoba Capital Region does not fall within the scope of this study. In determining that alternative construction materials may be both cost effective and ecologically beneficial, it should not be assumed that builders, designers and policy makers would readily adopt or utilize these techniques.

1.6 Significance of the research

This research demonstrates the value of integrating concerns of the environment and the economy with the health of the community. This is consistent with the global strategy towards sustainable development, the findings of Canada's National Task Force on Environment and Economy, and (from a provincial perspective) the Manitoba Capital Region Strategy, and the City of Winnipeg's Environmental Agenda for 2001.

One of the seven introductory goals of the Manitoba Capital Region Strategy (MCRS, 1996) is, "To promote diverse programs and initiatives that protect and improve the infrastructure and the natural and built environment of the Capital Region"(p.7). The issues addressed are consistent with this important objective. Policy Area 2 of the MCRS concerns itself with a sustainable settlement strategy. Fundamental to this section of the document is the protection of natural resources such as our waterways and natural habitat (p. 13). In addition, Policy Area 2 of the MCRS states, "settlements will minimize energy and water consumption, pollution and waste production. As, much as possible, pollutants and wastes will be managed at their source - in homes, in schools in the workplace" (p. 13). Because green roofs may help to mitigate the pollutants associated with stormwater runoff at their source, this research is a step toward achieving these objectives.

Section 2.2c of the MRCS advocates the inclusion of "water and energy conservation and waste minimization features into buildings, subdivisions and recreational open space development" (p. 16). Green roofs are documented as being an effective means of managing stormwater while increasing the energy efficiency of the buildings that they are installed on. By simulating the performance of green roofs, by assessing their future potential as an alternative means of conserving stormwater and by gathering evidence indicating gains in energy efficiency resulting from the green roof installation, this research represents a significant step towards achieving greater building-scale energy conservation and waste minimization.

Section 2.6 of the MCRS deals with surface and groundwater resources. The overall objective of this section of the document is to protect and conserve the region's surface and groundwater supplies in order to ensure that water reserves are safe, dependable and accessible (p. 20). This research document explores an alternative means by which to achieve this goal as laid out by the MCRS.

Section 2.9 of the MCRS is central to the current research. The underlying objective of this section states, "flooding and stormwater runoff shall be managed to reduce the adverse impacts on persons, property and the environment"(p. 22). The current study explores an ecologically sensitive means to mitigate the adverse impacts caused by flooding and stormwater runoff. In this respect, the findings and recommendations should be of interest to the City of Winnipeg and the flood-prone communities of the Red River Valley.

Policy Area 3 of the MCRS contains the objective, "to support and encourage a dynamic, growing and environmentally sustainable economy which ensures the quality of life and standard of living"(p. 24). The findings will contribute to a growing body of knowledge regarding a specialized roofing industry that is both economically and environmentally sustainable.

Most studies of green roofs have looked at scenarios which involve single buildings. By going beyond the scale of a single building and looking at the implications of utilizing green roof technology over a larger area, this study makes a significant step in generating new data. Living roof systems could play a future role in flood mitigation. The results of the research will be of critical significance to both the City of Winnipeg as well as the many communities located within the Red River Valley.

In February 2000, the City of Toronto's Environmental Task Force (ETF) proposed a plan entitled Clean, Green and Healthy: A Plan for an Environmentally Sustainable Toronto. This plan contains a list of recommendations that will lead Toronto towards a more sustainable future. The plan recommends that the city should address the potential for retrofitting green roofs and rooftop gardens on City-owned buildings and consider how green roofs and rooftop gardens can be implemented in new developments.

In addition to the above study, a 6,000 square foot green roof demonstration projected has been fitted onto the roof of the Toronto's City Hall (Peck, 2000). The research within this document will serve as a useful body of knowledge to the City of Winnipeg in prompting administrators to seek alternative methods of managing stormwater runoff. Should the City of Winnipeg draft a set of recommendations as has been done by the ETF, it is hoped that the information contained herein will surely serve as a helpful resource.

1.7 Dissemination of Results

The results of this research will be disseminated within the university community, architects, landscape architects, and members of the scientific community, engineers, developers, regional agencies, policy makers and government officials. Agencies that have expressed interest in this research include the Canadian Society of Landscape Architects and the Landscape Architecture Canada Foundation. Other organizations that may find the results useful include Manitoba Conservation, the City of Winnipeg, the Center for Indigenous Environmental Resources, and the

International Institute for Sustainable Development, the National Research Commission and the Green Roofs for Healthy Cities Coalition.

Chapter Two – Literature Review

The following is a summary of issues surrounding living roof systems. This literature review explores topics related to ecology, sustainable design and the role of the landscape architect in the sustainable design process. It also looks at rooftop history and typology, the costs and benefits associated with green roofs, conventional and green roof construction methods, and the role of green roofs in the management of stormwater.

2.1 Ecology, design and sustainability

Prior to our modern notions of ecological sustainability, Aldo Leopold, who coined the term "conservation" in the middle of the last century, recognized the importance of a land ethic. In time, the writings of Leopold caught the attention of philosophers, scientists, policy makers and designers alike. In turn, it led them to reevaluate their understanding of our relationship with the natural world.

> We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to see it with love and respect...That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly often forgotten.
>
> (Leopold, 1949, p.viii)

This thesis research seeks to expand our current knowledge of the synthesis between landscape and building design. Notably, the emphasis is placed on roof design and stormwater management. Many design philosophies ignore the pervasiveness of nature in our cities. The linkages between the city and the environment that support it are often ignored. This research seeks to facilitate an understanding of the benefits of altering the prevailing paradigms of thought on this topic. In so doing, it is hoped that rural nature and urban culture will no longer be viewed as disparate entities. In joining these two elements, the potential for creating healthier cities and a higher level of culture might emerge. The notion of ecological design is multifaceted and complex. Although a critical analysis of the ecological design process does not fall within the scope of this document, a brief summary of its components is essential.

Eckbo, Sullivan, Hood, & Lawson (1998) note that after thirty years of modern architecture, from the revolt of the thirties and the various revolts which occurred during the sixties, to the rigidity of the Beaux Arts world of design by precedent, the profession of landscape architecture was prepared for the new demands of the current "ecological revolt" (p.81). The authors go on to write that;

> The modern movement, sparked by an expanding number of talented new planners and designers, eliminated the traditional gap between axial and informal design, with its relatively limited vocabulary and developed in its place a free and asymmetrical geometry that made possible much greater respect for both natural and urban environments, and for variable forms in architecture and in the materials in nature.
>
> (Eckbo et al. 1998, p.81)

The Austrian artist (and designer of several widely popular green roofed structures) Friedrich Stowasser, better known as "Hundertwasser", embodies the spirit of the "ecological revolt" against modern architecture.

> ...The straight line is a man-made danger. There are so many lines, millions of lines, but only one of them is deadly and that is the straight line drawn with the ruler...The straight line is completely alien to mankind, to life, to all creation.
>
> (Rand, 1993, p.37)

Ian McHarg, one of the pioneers of ecological design and planning believed that the science of ecology was the "single indispensable basis for architecture and urban planning" (McHarg, 1969, p.328). In his 1969 essay entitled "An Ecological Method for Landscape Architecture", McHarg asserted that any landscape architect who commanded a thorough knowledge of the science of ecology would become the sole bridge between the natural sciences and the planning and design professions (p. 328). Throughout his career, McHarg remained steadfast in his assertions of the critical importance of the science of ecology in the ecological design and planning process.

> Landscape architects and ecological planners should become the physicians of the land. We should be healers, but we should be practitioners of preventative medicine. Medical doctors need to know human biology to practice their art. Similarly, we should be well versed enough in landscape ecology to be able to make diagnoses and describe interventions...To heal places landscape architects and ecological planners must not only have the knowledge and skill to make reasonable diagnoses and to prescribe sound actions, but also the courage to take on difficult challenges.
>
> (McHarg, I.L., & F.R. Steiner, 1998, p. 359)

With his seminal publication entitled Design With Nature, McHarg developed a method of mapping in which a broad selection of human altered and unaltered land types are assembled as a series of overlay maps. This mapping technique charts the physical landscape using five separate categories; physiography, geology, plant and soil dispersal, human land use, and scarce phenomenon (McHarg, 1969, p.329). By analyzing the overlays of these interdependent systems, the suitability of a site for a particular form of development is revealed. As the precursor of present day

Geographic Information Systems, McHarg's method of land-use analysis is perhaps the single most important tool in urban planning today (Shulman, 2000).

McHarg's method of ecological planning has been widely accepted by many planners and designers. Nevertheless, McHarg does have his critics. Corner (1997) contests that, although the ecological planning process as conceived of by McHarg is of value, McHarg's interpretation of the term "ecology" is too simplistic. Corner asserts that:

> Although ecology has surfaced in modern landscape architectural discourse, a culturally animate ecology – one that is distinct from a purely scientistic ecology has yet to emerge…an eco-imaginative landscape architecture would be creative insofar as it reveals, liberates, enriches, and diversifies both biological and cultural life.
> (Corner, 1997, p.87-88).

Although McHarg's land-use analysis is meant to improve our understanding of biophysical and social process, Corner asserts that it is too mechanistic. In focusing on the land while excluding the cultural factors behind our ecological crisis, McHarg has subsequently diluted the social factors that have precipitated our current condition.

> If landscape architecture is to concern itself with the "ecological crisis" and other difficulties of human life upon the earth, then it must recognize expeditiously how the root cause of environmental (and spiritual) decline is buried in the complex foundations of modern culture, particularly its political-economic practices, its social institutions and the psychology and tolerance of much of its citizenry.
> (Corner, 1997, p.90)

Further to his argument, Corner views contemporary models of landscape architecture as being too objectivist and instrumentalist. That is, these models have placed an emphasis on objective reality rather than the thoughts and feelings that have precipitated our current condition (1998, p.82). Landscape architecture, according to

Corner, is instrumentalist because the validity of our actions is judged solely by their results. This has subsequently led to a lack of inventiveness in design (1998, p.82).

> The failure of landscape architecture between ecology, creativity and landscape means that either this is an incongruous mix or a potential that might inform more meaningful and imaginative cultural practices than the merely ameliorative, compensatory, aesthetic, or commodity oriented...I argue that ecology, creativity and landscape architecture must be considered in terms other, or greater than those of visual appearance, resource value, habitat structure or instrumentality.... ecology, creativity and landscape architecture are metaphorical and ideological representations, they are cultural images or ideas...What is important or significant here is how ecology and landscape architectural design might invent alternative forms of relationship between people, places and cosmos. Thus, the landscape architectural project becomes more about the invention of new forms and programs than the merely corrective measures of restoration.
>
> (Corner, 1997, p.82)

Corner recognizes the role of the science of ecology in planning and design. However, he notes that planners and landscape architects often fail to recognize that the metaphorical characteristics of ecology embody our notion of reality (1997). Many different social groups represent, relate to, and speak of nature in ways that embody a richness that a purely scientistic ecology is incapable of embracing or acknowledging (1997). Although the methods used by McHarg acknowledge culturally significant uses of land, Corner emphasizes the profound importance of understanding the cultural interests and ideals that have shaped our world. Corner reaffirms the need to recognize the "cultural harvest" of the land that Aldo Leopold spoke of fifty years earlier. Corner acknowledges the ameliorative worth of McHarg's method, however views this method as being mechanistic, impersonal, and reflective of our advancement of measures based on utility, production and commodity.

> In reducing the living world to ingredients that could be easily measured and graphed the ecologist was also in danger of removing all

> the residual emotional impediments to unrestrained development…to describe a tree as an oxygen producing device or a bog as a filtering agent is a violence that is debasing to being itself.
> (Corner, 1997, p.91)

In response to earlier models of ecological planning viewed as being reductionist and devoid of any significant reference to social patterns or behavior, Corner asserts the relevance of social ecology to landscape architecture and planning. Social ecologists are critical of the social practices of domination over nature, commodification and instrumentality. Social ecology focuses on the techno-economic effects of our modern cultural paradigms. Lastly, social ecology asserts the power of the human imagination and of creativity (1997).

This section has focused on issues of ecological planning. We must now consider the design phase and the role that ecology plays with respect to the design of a landscape. Common notions of ecological design are a transformation of Ian McHarg's ecological approach to planning. Franklin (1997), a landscape architect, author, and colleague of McHarg's states that, "beyond data collection, mapping parameters and creating overlays, sustainable design requires the designer to interpret forms and patterns of a place and to tell its story – what the site was, how it has changed and the directions in which it is likely to go" (Franklin, 1997, p.268). Franklin asserts that in uncovering the history of a site past connections are uncovered. The more vividly the design is able to portray the site character; a higher quality of design will emerge and grow from our understanding of the site.

To McHarg, ecological design followed the planning process and introduced the subject of form (Franklin, 1997). McHarg asserts that nature is full of examples of adaptive design, and that the goal of the informed designer should be to follow these examples found in nature.

> Should we pursue this track we would reconsider membranes. The giant clam and nudibranch have incorporated chloroplasts. Why not build membranes, walls and roofs? Consider vegetation on walls and roofs to add carbon fixing and minimizing carbon dioxide.
> (McHarg, 1997, p.329)

Although McHarg has always held that nature informs design, others assert that to derive design out of nature limits one's creativity. McHarg notes in his 1997 article entitled "Ecology in Design", that despite a new tendency by some architects to reject ecology and to emphasize art exclusively, such an approach is both tragic and ironic. McHarg states his belief that the profession of landscape architecture is lagging behind other design professions with respect to the imperative of sustainability "when so many world leaders are calling for sustainable development, when architects are issuing green manifestos, and professional associations in architecture and engineering are refocusing their attention on the environment" (McHarg, 1997, p.322).

Corner (1997) asserts that ecological design should inform a liberated form of landscape architecture whereby the way "in which calcified conventions about how people live and relate to land, nature and place are challenged and the multivariate wonders of life are once again released through intervention" (p. 100). A truly ecological landscape architecture, according to Corner, might be less about the construction of finished works "and more about the design of process, strategies, agencies and scaffoldings – catalytic frameworks that might enable a diversity of relationships to create, emerge, network, interconnect, and differentiate" (1997, p.102).

Since 1953, Hundertwasser has painted and designed according to his own notion of the term "ecology". Hundertwasser asserts that, long before the emergence of ecology as a mass movement, the forms created by his work adhered to his notion of creative ecology and socially inclusive design. In conversation with Harry Rand, Hundertwasser states, "This term ecology was introduced, and the word ecology can be considered a mistake, because ecology means nature and the cycle of nature, but one important factor is left out by the ecologists, and that is the feeling of being creative" (Rand, 1993, p.64).

Other noted and respected ecological designers, such as Anne Whinston Spirn, focus not only on our understanding of the site but also on the way in which the user interacts with that design. In embracing both [building] architecture and landscape architecture, Spirn's ecological vision asserts that buildings "exist within a landscape are connected to it by the process of nature and by our actions as humans, who inhabit both" (1990, p.41).

> Too much architecture today is preoccupied with a self-referential discourse and a self-conscious dialogue with high culture. It is cocktail-party architecture – noisy, posturing, trying desperately to make an impression, to stand out, to be talked about, to be desperately interesting...it has lost touch with what architecture is all about: creating a vital, humane habitat that artfully expresses the conditions of its time and place and the dreams of its people.
> (Spirn, 1990, p.37)

Spirn believes that architecture is becoming a tool that serves to alienate us from our fundamental connection to nature (1990, p.38). In so doing, our architecture has created an illusion whereby we are led to believe that we have achieved a high degree of control over nature.

Koh (1982) states that McHarg's approach toward design is important for its social relevance and for the stress that it placed on the importance of a holistic and evolutionary worldview (1982). Accordingly, Koh notes that ecological design is an inclusive culture rather than an exclusive art. Although the term "ecological design" is commonly used to denote any design that is sensitive to ecological processes, Koh suggests that ecological design includes the physical, biological, cultural and psychological realms. The energy efficiency of a building and the protection of the human environment provided by the structure are considered to be complementary outcomes of the ecological fit between the building and its natural and cultural environments. The attention of the ecological designer is less on the environment as being a product and focuses more on the interrelationship between humans and their environment (Koh, 1982). According to Koh, ecological design is the antithesis of the paradigm of Modern environmental design. Koh defines Modern environmental design as being both reductionist and exclusive. It is reductionism in its conviction that man and nature can be reduced to their most basic elements. It is exclusionist in that "the designers were the only ones, they believed, who could and should shape and determine our living environment"(Koh, 1982, p.77). In his belief that ecological design should provide the external structure from which a diversity of relationships "create, emerge, network, interconnect, and differentiate"(p.102), Corner (1997) takes Koh's notion of inclusivity in design even further. Not only is Corner's ecological design inclusive, it is also open ended, leaving future generations with the framework by which to continue to shape their own reality.

Similarly, Eckbo, Sullivan, Hood, and Lawson (1998) assert the social relevance of the ecological designer. The ecological designer "should be the moderating leader and persuader among the social and natural forces that may generate conflict.... He or she must be constructive, inventive and agile" (Eckbo et al., p. 173). Eckbo et al. note that the ecological designer is confronted by many differing worldviews and will inevitably have to choose a design philosophy that best suits their personal beliefs.

> The good designer knows that whatever may result from confrontation between ecological consciousness, and dominant economic determinism there will always be work, opportunity and fulfillment. Early on, designers must decide on how much corruption they can opt for, by favoring the "right clients", and how much social ecological consciousness they can maintain to offset the corruption. This simplistic morality tale formulation makes it sound like an obvious decision. But it is not, nor has it been.
>
> (Eckbo et al., 1998, p.174)

The notion of ecological design runs parallel to the paradigm of sustainable development. Taken in its broadest context, sustainable development promotes development in which life-sustaining processes occur in concert with continued development (Van der Ryn & Cowan, 1996). The notion of sustainable development can be considered from two perspectives, technological sustainability and ecological sustainability. According to advocates of technological sustainability, every ecological problem can be resolved through advancements in science, international treaties or through the dynamics of the open market. Ecological sustainability, on the other hand, seeks alternative methods to conventional practices of shelter, energy use, agriculture, resource use, urban design, transportation and countless other facets of design. Although both of these categories share an awareness of the urgency of global ecological problems, both are distinct in their vision of a sustainable future.

The proponents of technological sustainability assert that radical changes in the way we live are unnecessary. Instead, better management, better technology, and open global markets - to aid in the diffusion and trade of products, ideas and management practices - will enable the fine-tuning of the interface between people and the biosphere. The critics of technological sustainability assert that the details of culture and community are neglected in an attempt to manage systems on a global scale, thereby leading to global-scale inequity (Van der Ryn, & Cowan, 1996).

Paul Hawken, Amory Lovins and L. Hunter Lovins (1999) assert that conventional capitalist economic systems can be summed up by the following universally accepted principles.

- Economic progress can best occur in a free market system of production and distribution where reinvested profits make labor and capital increasingly profitable.
- Competitive advantage is gained when larger, more efficient plants manufacture more products to expanding markets. Growth in total output maximizes human well being.
- Any resource shortages that do occur will elicit the development of substitutes.
- Concerns for a healthy environment are important but must be balanced against the requirements of economic growth, if a high standard of living is to be maintained.
- Free enterprise and market forces will allocate people and resources to their highest and best use.

(Hawken, A. Lovins, & L.H. Lovins, 1999, p.6)

In their book, Natural Capitalism: Creating the next industrial revolution, Hawken et al. (1999) introduce four central strategies of natural capitalism. These strategies are meant to enable countries, communities and companies to operate by behaving as if all forms of capital are of value. The strategies used include methods appropriate to the notions of both ecological sustainability as well as technological sustainability. The principles outlined by Hawken et al. recognize the importance of rethinking both product design and the ways by which we manage the inputs and outputs of manufacturing. The authors believe that by valuing all forms of capital (including natural capital), a perpetual annuity of social and natural resources will become available in order to serve a growing population.

The first principle of natural capitalism suggested by Hawken et al. is known as "radical resource productivity". By increasing our efficiency in how we use natural resources, we will slow resource depletion, lower pollution and increase levels of employment (p.10). According to the authors, nearly all environmental and social harm, is an artifact of uneconomic and wasteful use of our resources. The second principle put forth by the authors is that of biomimicry. The authors state that "Eliminating the very idea of waste – can be accomplished by redesigning industrial systems on biological lines that change the nature of industrial process and materials, enabling the constant reuse of materials in continuous closed cycles, and often the elimination of toxicity" (p.10). Next, the authors note a need to change from a producer and consumer economy to that of a service and flow economy, "This concept offers incentives to put into practice the first two innovations of natural capitalism by restructuring the economy to focus on the relationship that better meet customers' changing value needs and to reward automatically both resource productivity and close-loop cycles of materials use" (p.10). The fourth and final guiding principle is the notion of investing in natural capital. By reinvesting in sustaining, restoring and expanding our stocks of natural capital, the biosphere will eventually be capable of producing more abundant "ecosystem services" and natural resources (p.11).

Indeed, it can be observed that Hawken et al. do not necessarily assert that there are limits to growth or productivity. Instead, the processes involved in productivity should be rethought so as to engender and incorporate natural process. In doing so, we will no only be enhancing ecosystem health and productivity, we will be creating jobs and continuing to grow. Authors such as James Corner, who has asserted that the root cause of our environmental and spiritual decline can be found in the complex foundations of our modern political economy, would not agree to the principles as laid out in Natural Capitalism. Rather than altering a paradigm that many see as the root of our current state of ecological decline, Hawken et al. substitute alternative inputs into an existing political and economic structure. The notion of developing and marketing the services provided by ecosystems might be viewed by James Corner as being both spiritually devoid and debasing to life itself.

The proponents of ecological sustainability assert that there are limits to the capability of technology and global management practices in solving environmental problems (Franklin, 1999). Rather than focusing on global management strategies, the creation of a sustainable world is dependent upon a careful consideration of scale, community, local knowledge and the wisdom of nature. Franklin (1999) asserts that ecological sustainability is holistic in its approach. Rather than being single focused and reductionist, an ecologically sustainable approach to design exists in one's ability to solve problems that are multidimensional in scope. All too often, single-focus design solutions merely solve discrete problems while creating new ones. Ecological sustainability is less positivistic than technological sustainability. It recognizes the importance of studying the interrelationship of humans and the environment rather than perceiving them as independent entities.

Design is defined as the shaping of matter, energy and process with the intent to achieve a desired condition. Design therefore works to integrate culture and nature via flows and exchanges of materials and energy. The way in which we treat the land is clearly an issue of design.

Van der Ryn and Cowan (1996) note that the environmental crisis is a design crisis. The urgency facing our environment is the outcome of how things have been made, how buildings have been constructed and how landscapes have been utilized. This assertion is clearly contradictory to that of the proponents of technological sustainability. In asserting that design reflects the culture of our time, and that the culture of our time is based on the precepts of what we hold as universal truths, it is evident that the present form of shaping our world is incompatible with nature's own strategy of design. By living and growing at a scale and pace that local ecosystems are unable to sustain, and by degrading the living world around us, we are degrading our own health.

Van der Ryn and Cowan (1996) suggest five principles of ecological design, a summary of these principles is as follows:

- Ecological design solutions begin with an intimate knowledge of place. By being sensitive to the nuances of place, we can inhabit without destroying.
- By making process and natural cycles visible, the designed environment will be brought back to life.

- By working with living processes, the needs of all species are respected. Thus, the designed environment serves to inform us of our place within nature.
- By tracing the environmental impacts of design, we gain the tools necessary to determine sound design alternatives.
- Ecological design is inclusive. As people work together to heal their surroundings, they also heal themselves.

(Van der Ryn and Cowan, 1996,pp.54-56)

In an effort to relate ecological design to the practice of landscape architecture, Franklin (1999) asserts similar principles to those stated above. Franklin notes that there is no unified system from which there can emerge one rigorous ecological design prescription. Accordingly, the underlying key to ecological design is a whole systems approach. Design professionals frequently gear themselves toward finding single-focus solutions that seem reasonable from the view of the individual discipline. However, how we design and alter the land requires multi-dimensional solutions.

Franklin (1999) offers several key components as being integral to a holistic approach towards the ecological design of a landscape. Firstly, the values and functions critical to the integrity of the site must be protected or enhanced through the development of the site. Reconnecting fragmented habitat and establishing native species are singled out as important landscape design goals. Franklin also notes that by determining the inherent natural character of a site, the social and cultural forces of the site will emerge as being equal in significance to other patterns found in nature. Franklin adds that ecological design solutions must craft adaptive strategies to design problems. Adaptive strategies must solve more than one problem at a time. For example, design solutions need not be zealous in their attempt to reestablish natural conditions. Rather, maintaining natural processes can also be achieved by finding solutions to site infrastructure requirements that are based on natural models.

According to Van der Ryn and Cowan (1996), we are now at the threshold of the second generation of ecological design. Earlier examples of ecological design solutions were based on small-scale experiments and prototypes. The second generation is not an alternative to dominant technology. Instead, it is the foremost path in their evolution.

> The second generation of ecological design must effectively weave the insights of literally dozens of disciplines. It must create a viable ecological design craft within a genuine culture of sustainability rather than getting entangled in interdisciplinary disputes over turf wars. It is time to bring forth new ecologies of design that are both rich with cultural and epistemological diversity.
>
> (Van der Ryn and Cowan, 1996, p. 32)

A design ethic that recognizes the importance of the interaction of climate, topography, soil, vegetation, wildlife and human communities is indeed an ethic driven by diversity. Ecological design must involve people from the sectors of agriculture, architecture and planning, industry, and wildlife professionals (Franklin, 1999). In realizing the interconnectedness of growth and ecological process, a design framework that addresses our evolving core of ecological values and beliefs will continue to emerge.

> On any basis from cultural to survival, it is apparent that these two lines [culture and nature], have to reconnect in some way. Is it possible to conceive of human culture over the twenty-first century remarrying nature, after fifty centuries of expanding alienation, and producing an new, revitalized family of truly designed natural environments?... We are irreversible optimists in the central areas of human vision and cultural flexibility. I believe that they will overcome the greed and skullduggery of the business world in time to rescue nature from destruction and produce a new more marvelous integrated world.
>
> (Eckbo et al., 1998, p.81)

Indeed, as we enter the twenty-first century the professions of landscape architecture, interior architecture, building architecture, urban planning and urban design are at a significant junction. If these design professions choose to embrace ecological design and ecological planning, then these professions will most certainly assume a leadership role in contemporary society. If these professions choose to turn inward and ignore their larger responsibility to the public good, "then [they] will become marginalized and less relevant" (Thompson & Steiner, 1997, p.4). The recommendations made by this research will add to the body of knowledge that is currently available to those individuals who choose to adopt ecological design strategies.

2.2 Architecture, culture, and rooftop typology

In building our homes, our businesses and out civic infrastructure, we have come to create much more than mere dwelling places. We have been marking our place within nature. As we have continued to populate our earth, and construct our places of dwelling, we have all become ad hoc architects of our environment. Though often neglected as an important and culturally significant element of our landscape, our rooftop surfaces have played a significant role in shaping our cities. Christopher Alexander (1977) notes that "A vast part of the earth's surface, in a town, consists of roofs. Couple this with the fact that the total area of a town which can be exposed to the sun is finite, and you will realize that it is natural and indeed essential to make roofs which take advantage of the sun and air" (p. 576).

What is the roof? How is the character and quality of a place reflected by the architecture of the rooftop? Watts (1961) in his article entitled "Reading the Roof Lines of Europe" writes,

> Igloos, teepes, prairie sod-huts, hogans, pueblos – have ecology in their rooflines... These shelters are oriented to a landscape, to weather and to local materials.... No such orientation marks North American rooflines. They offer no comment on wind or rain, or local quarries or forests. They speak only of style and solvency. A roof has become only another piece of merchandise, as unrelated to its environment as its owner's creased trousers, his wife's spiked heels or their son's space suit.
>
> (Watts, 1961, p.169)

The structure, pitch, overhang, chimney shape and type of material used on a roof surface best describes the various rooftop conditions found within Europe. In Normandy, roofs of moderate pitch and overhang with small and simple chimneys dominate the landscape. This is evidence that rainfall and temperature are moderate in both degree and quantity (Watts). The thin silky groundcovers found within the local beech forests are represented in the color and lines of the roofs of Normandy (Watts).

The mansard roofs found in Paris are as divorced from the environment as city life is from the countryside. Watts notes that these roofs reflect the ornamental pedigree landscape. Like the French poodle and the linden tree, the rooflines of Paris reflect an attempt to separate one's self from nature. "Here one eats trout from the north, with almonds from the south, and beef from Argentine, and oranges form Africa" (p.170). In Provence, the mistrals and bitter winds that blow from the Alps have led to roofs with narrow eaves and walls with no windows. Many roofs have rocks piled upon them (Watts).

In a study of the roofs of England, Watts notes that many cottages wear their roofs like "stocking caps pulled low around their ears" (p.179). While in Norway, "usually the pitch of the roof is steep enough to let the snow and the rain slide off; but sometimes a farmer builds a roof with little pitch so that he can cover it with sod. The sod roofs are green and often flowery, and sometimes a goat grazes there" (p.176).

Watts provides an insightful breakdown of the roof types of Europe. The author notes the influence that culture and physiography have on rooftop design. However, in North America and in newer European developments, "technology had given us the ability to create media that are facile and transportation that is efficient" (p.176), thus roofs have become a product of economic efficiencies rather than culture and region.

Watts gives examples of how building rooftops are inexorably linked their natural environment through design. By demonstrating that there is a clear relationship between architecture and nature, and that this relationship creates rooftops both unique in form and indicative of place, it is hoped that such examples will inspire designers to create buildings that better reflect local context, culture and environment.

2.3 The history of rooftop vegetation

Roof gardening has existed in the Mediterranean since the invention of the earthenware pot. Mild winters and sparse rain eliminated the need for pitched roofs. The only limiting factor in the development of the flat roofed buildings found in Mesopotamia was the lack of adequate wood building materials (Whalley, 1978). The earliest known use of rooftop vegetation can be traced back to approximately 2500 BC. Ancient temples (known as Ziggurats) containing vegetation on their roofs were believed to have been constructed by the people of Mesopotamia, a civilization located in present day Iraq that preceded Egypt. The Ziggurats, or pyramidal mounds are much different than the pyramids of Egypt. In essence, Ziggurats are mud-brick temples that served the symbolic function of the meeting place between the heavens and earth. In a recent excavation of a ziggurat built by a Mesopotamian king some 2,500 years ago, the archeological team determined that the Ziggurat had three staircases. The first two levels were covered with bitumen. The bitumin was used then, as it is today, to provide waterproofing of rooftop surfaces. It is most likely that trees and shrubs were planted on the levels of the Ziggurat that had been coated in bitumen (Associated Press, 1998).

The most spectacular and historically renowned rooftop gardens were the Hanging Gardens of Babylon. Accounts indicate that King Nebuchadnezzar, who ruled the city for 43 years starting in 605 BC, built these gardens. Although there is some speculation that these gardens may have been built by the Assyrian Queen Semiramis in 810 BC, this theory is considered to be less probable by archeologists and historians alike (Krystek, 1998).

According to historical accounts, the gardens were built to console Nebuchadnezzar's homesick wife, Amyitis. As daughter of the king of the Medes, Amyitis was married to Nebuchadnezzar to create an alliance between two nations.

> The land she came from, though, was green, rugged and mountainous, and she found the flat, sun-baked terrain of Mesopotamia depressing. The king decided to recreate her homeland by building an artificial mountain with rooftop gardens. The Hanging Gardens probably did

not really "hang" in the sense of being suspended from cables or ropes. The name comes from an inexact translation of the Greek word kremastos or the Latin word pensilis, which mean not just "hanging", but "overhanging" as in the case of a terrace or balcony. The Greek geographer Strabo, who described the gardens in first century BC, wrote, "It consists of vaulted terraces raised one above another, and resting upon cube-shaped pillars. These are hollow and filled with earth to allow trees of the largest size to be planted." The pillars, the vaults, and terraces are constructed of baked brick and asphalt.... Construction of the garden wasn't only complicated by getting the water up to the top, but also by having to avoid having the liquid ruin the foundation once it was released. Since stone was difficult to get on the Mesopotamian plain, most of the architecture in Babel utilized brick. The bricks were composed of clay mixed with chopped straw and baked in the sun. The bricks were then joined with bitumen, a slimy [petroleum based] substance, which acted as a mortar. These bricks quickly dissolved when soaked with water. For most buildings in Babel this wasn't a problem because rain was so rare. However, the gardens were continually exposed to irrigation and the foundation had to be protected. Diodorus Siculus, a Greek historian, stated that the platforms on which the garden stood consisted of huge slabs of stone (otherwise unheard of in Babel), covered with layers of reed, asphalt and tiles. Over this was put "a covering with sheets of lead, that the wet which drenched through the earth might not rot the foundation. Upon all these was laid earth of a convenient depth, sufficient for the growth of the greatest trees. "

(Krystek, 1998, p.1)

Consistent throughout the history of rooftop gardens is the need to develop a means by which to eliminate the infiltration of runoff. The Hanging Gardens of Babylon were unique in that the structures that they sat atop were not subject to significant amounts of rainfall. Rather, the gardens were heavily irrigated from water of the Euphrates River delivered by a semi-mechanical irrigation system. The means of ensuring waterproof protection for the structure that supported these gardens had to be developed. Like the Mesopotamians, the architects of Babel made use of naturally occurring asphalt to protect brickwork from damp penetration.

In classical Rome and Pompeii, green roofs were known to exist as a response to population pressures in urban areas (Peck, 1999). In Pompeii, shopkeepers grew vines from their upstairs balconies. The ancient historian Pliny wrote of trees being imported for the specific purpose being planted on green roofs (Peck). Although roof gardens were built for both private villas and tenement buildings (Villager, 1986), theatricality and prestige (rather than necessity) were the dominant motives behind the development of classical rooftop garden architecture (Whalley, 1978). From the tree planted circular terraces of Augustus or the Byzantine balcony gardens of Justinian I, all were outwardly posturing monuments meant to signify authority, control and eminence.

As a roofing material, sod has been used almost as long as humans have constructed buildings. In the Nordic countries and in Northern Europe, where the climate was colder and wetter than that of the Middle East, and where building materials were more plentiful, pitched roofs and warm buildings were a necessity. The availability of strong building materials enabled builders to cover these rooftops with sod (Whalley, 1978). Sod roofed houses in excess of three hundred years old can be found in Iceland and Scandinavia. In addition to sod, sea kelp has been used for hundreds of years as a means of insulating rooftops while providing a medium for plant growth (Donnelly, 1992). Rooftop gardens are also known to have existed in pre-Colombian Mexico, India, and in some of the Spanish homes of sixteenth and seventeenth Mexico (Peck, 1999). In Russia, hanging gardens were incorporated into the design of the seventeenth century Kremlin (Peck, 1999).

In Tanzania, grass roofed houses are still used to keep houses cool in exceedingly hot temperatures (Kuhn, 1996). The earliest use of sod roofing in Canada is traced to the early Icelandic settlers of Newfoundland. The settlers of the Canadian prairies and mid-west United States constructed some of their first homes with walls and roofs of sod. These early prairie dwellings used wood slat roofing covered in a layer of living prairie grasses.

Vernacular buildings are more than quaint reminders of a past age. As builders were limited to using locally available materials, these structures are indicative of a time when sustainable building practices were essential to survival (Pearson, 1995). Vernacular buildings hold many ecological lessons for us. A reexamination of early living environments, and those still built by primitive peoples of today, reflect a new phase in design (Lyle, 1985). The application of accumulated knowledge leads to well-informed design. Such design is rich in both meaning and in its suitability to local environmental conditions.

As a result of the revival of Renaissance architecture several structural technologies made their way into northern Europe. The cantilevered stone balcony, a favored motif of the Georgian architecture of northern Europe, provided an external planting space without causing undue structural and moisture-damping problems. Renaissance revivalists returning home from the Grand Tour of continental Europe were greatly impressed by the Italian High Renaissance fondness of grottos, with planted terraces above. These aristocrats then “attempted to incorporate similar ideas into the modernization of their family seats” (Whalley, 1978, p.7). Renaissance architecture, such as the rooftop garden of Cosimo de’Medici’s villa Careggi, renowned for its diverse botanical collection, villa Careggi had a profound influence among those privileged few who partook in a Grand Tour (Whalley). Although the tradition of the Grand Tour played a significant role in the recognition and acceptance of rooftop verdure, Whalley notes that this development did not come without its without its costs.

> That roofing technology lagged behind these cultural developments was all too evident in Ludwigg II's winter garden, built over a wing of his Munich palace and finished in 1874. Designed to surpass the exoticism of his father's winter garden, and built over a different wing of the palace, it contained a considerable water feature and was entirely covered by a glazed roof. Despite a system of thick copper plates laid over stone vaults, seepage through to the rooms down below was extensive and the structure had to be demolished in 1897.
> (Whalley, 1978, p.7)

In the article entitled "The landscape of the roof" by J.M. Whalley, the author states that a major turning point in rooftop landscape design took place at the 1867 Paris exhibition. It was then that Carl Rabitz, a German master builder, exhibited a plaster model of a roof garden designed as a part of his Berlin residence.

> Here was seen the first bourgeois roof garden, set in northern Europe, on a purpose-designed flat roof intended principally for leisure use during the summer months. This roof construction used Rabitz's patented invention of vulcanized cement. Widely reported in the papers, reviews of the scheme touched on themes that are still expounded in the cause of roof landscape; beautification of the city landscape, rescuing leisure space from congested city development, increased roof insulation and stabilization of the effects of temperature changes on roof structure and the internal environment.
> (Whalley, 1978, p.8)

As history progressed, the flat roof became a central design motif in the modern movement "With its determination to reduce the redundancy and decoration of nineteenth-century design to greater levels of geometric simplicity and cubic purity" (Whalley, p.8). Le Corbusier and Frank Lloyd Wright are famed for being the first modern architects to incorporated green roofs into the design of their buildings. Le Corbusier wrote of his vision of roads placed on greened rooftops. In his book A New Architecture, his fifth point was devoted to roof gardens (Curtis, 1986). According to Whalley, Corbusier's green roof on his Villa Savoie at Poissy, "reveals that roof landscape in the modern movement tended to be somewhat of a half measure, because the architect was too obsessed with his formalist intentions to tolerate the true exuberance of plant growth" (Whalley, p.8).

Independent of the European based modern movement, Frank Lloyd Wright "truly developed roof landscape as an integral element in modern design" (Whalley, p.8). With its emphasis on integrating building and landscape, Wright's use of green roofs stemmed from his American Prairie School philosophy (Hoffman, 1995), and in turn influenced more contemporary examples of modern design (Whalley, 1978).

> The lines of his balcony and fascia upstands, softened in his delicate pencil perspectives by cascading foliage, became a favored motif in modern design board sketch designs. Aided by more reliable roof landscape technology, the contemporary preoccupation with heavily planted stepped sections has resulted in schemes like Gateway House, Basingstoke (architects : Arup Associates), the Weyerhauser building in Washington State (landscape architects : Sasaki, Walker Associates), and the Muhlehalde housing scheme, Umiken-Brugg, Switzerland (architects : Team 2000).
>
> (Whalley, 1978, p.8)

Independent of the changes in the form and appearance of architecture over the past century, Whalley notes that there have also been significant changes in building and roofing technology. These changes in technology have enabled the construction of flat roofed high-rise buildings with clear vantage points of the rooftops below.

> The systematic application of the roof landscape was made possible this century by the development of petroleum-based damp-roofing technologies and wide span concrete and steel structures. Therefore city center high rise developments have encouraged the modern roofscape as something to be looked down upon from adjoining buildings.
>
> (Whalley, 1978, p.10)

The modern day European experience in the growth and development of a green roof industry has been both progressive and enterprising. This reaction is undoubtedly owing to the sheer extent of non-porous surfacing and the limited provisions made for the incorporation of verdure within the urban environment.

Villager (1986) notes that this condition grew out of the expansion of medieval cities. The areas surrounded by the walls of the medieval city were exclusively non-porous and green space was viewed as an amenity available - and easily accessible - outside of city walls. However, "As cities expanded outside of walls, they agglomerated all the hard surfacing, this now stretches on for miles" (Villager, 1986, p.2). Prinz et al. (1981) note that since the foundation of towns, builders have thought in terms of permanence. The hardest materials, ideally stone, have been used for building. The authors state that prior to the 1920s the only urban green spaces to be found in Germany were avenues, demolished fortifications, and parks which dated back to the time of absolutist rule (p.2). The reconstruction that followed World War II saw a massive decline in urban green space in European cities. This has led to the creation "green channels" as means of allowing fresh air passage into German cities (Prinz et al., 1981).

In many parts of Europe, where urban sprawl has become a serious problem, living roof systems have been adopted out of a need to minimize the ecological impacts associated with urban growth. Indeed, as times have progressed, technology has enabled us to engineer new materials in a more cost effective manner. Prinz et al. (1981) note that in principle "The hardening and petrification has ever increased..." (p.6). In several northern German cities, by-laws have been legislated to ensure that all new industrial buildings are designed and built with green roofs (Kuhn, 1996). In 1989, there were an estimated one million square meters of low-maintenance grass roofs under construction in Germany (Johnston & Newton, 1991). By 1996, this number had expanded to an astonishing ten million square meters (Peck, 1999).

> This tremendous growth was stimulated largely by state legislation and municipal government grants [for green roof construction]...Other European states and cities have adopted similar types of support and policy, with several mid to large-sized cities incorporating roof and vertical greening into their by-laws and planning regulations. Vienna, Austria provides subsidies and grants for green roof installations at three stages of the project – planning, installation and three years after installation to ensure proper maintenance and use. In Stuttgart, Germany, for example, a 1989 municipal by law was passed requiring the installation of a grass roof on all flat-roofed industrial buildings. A similar by-law was passed in the city of Mannheim, Germany.... As a direct result of government policy and program support in Europe, a new industry has been created for plants and material suppliers, roofing professionals, installers and maintenance crews – the "green roof industry". In Germany, France, Austria, Norway, Switzerland and other European states, green roofs have become a commonly accepted feature in the construction industry and a welcome feature of the urban landscape.
>
> (Peck, 1999, p.12)

The acceptance and development of green roofs in North American has progressed at a different pace and under a set of circumstances that are, by no means, analogous to the pace of green roof development in Europe. With the widespread acceptance of modern architecture and the subsequent technological advances in roofing system technologies, the roofscapes of North American towns and cities are evidence of our affinity for flat roofs. It appears that urban density has played less of a role in stimulating North America's recent interest in green roofs than it has in Europe. Rather, the largest motivator behind North America's recent interest in roof greening can be found in the public's increasing desire to protect our environment from the ecological problems associated with urban growth.

With the exception of the many intensive green roofs designed on top of buildings constructed in the 1960s and 1970s, the use of extensive green roofing as a means by which to counter the negative consequences of urban sprawl is a very recent phenomenon in North America. The most prominent extensive green roofing projects being undertaken in North America are demonstration projects, civic buildings and commercial buildings. These include the Toronto City Hall green roof infrastructure demonstration project (7,000 square feet), the Chicago City Hall green roof demonstration project (10,000 square feet.), and the University of Laval green roof demonstration project (The Green Roof Infrastructure Monitor [GRIM], 2000). Green roof infrastructure demonstration projects slated for construction in 2001 include the Eastview Neighborhood Community Center (Toronto), and two Toronto high schools (a project sponsored by Toronto Hydro Energy Services Inc).

The National Research Council's Institute for Research in Construction plans to conduct research into the energy efficiency and capability of green roofs to retain stormwater. The project involves the use of two identical buildings in Ottawa, with roof areas of approximately 1,000 square feet, one of which is to be fitted with an extensive green roof while the "control building" will not be altered (GRIM, 1999).

Recent civic and commercial green roof projects that have occurred in North America over the past decade include; an 8,500 square foot green roof placed on the roof of a high rise building owned by the City of Portland Building Authority, the 60,000 square foot green roof on the newly constructed Mountain Equipment Co-op building in Toronto, the Vancouver Public Library, and the New Merchandise Lofts of Toronto (GRIM, 2000). Well-known green roof projects that were constructed in North America in the late 1970's include the Kaiser Center (Oakland), the Oakland Museum, the Hotel Bonaventure (Montreal), and Ryerson Technical Institute (Toronto).

With respect to future projects, a green roof of over 450,000 square feet is to be included as part of the Ford Motor Company's expansion of its assembly plant in Dearborn, Michigan. Slated for completion in 2003, this project will be the world's largest green roof ever used on an industrial building (GRIM, 2000).

Although steadily gaining in momentum, the widespread acceptance of green roofs in North America has yet to occur. The above synopsis suggests that that the existing stock of buildings in North America that have been fitted with green roofs tend to be located around the Great Lakes or on the West Coast. With the exception of the Ducks Unlimited Head Office located at Oak Hammock Marsh (Manitoba), the prairie provinces of Canada have yet to truly explore the use of this technology.

J.M. Whalley was the first author to look toward the future of extensive green rooftops and comment on the likelihood of these systems becoming accepted by designers and contractors. Although North Americans have been comparatively slow in adopting this technology, much of what Whalley predicted in 1978 holds true today.

> It is likely that developments in lightweight planting media and in drainage systems will make it possible to achieve afterthought landscape schemes on existing flat roofs with a reasonable feeling of depth to the landscape...If such systems gained market acceptance, roof landscapes could become a standard element in many large building projects with flat roofs.
>
> (Whalley, 1978, p.10)

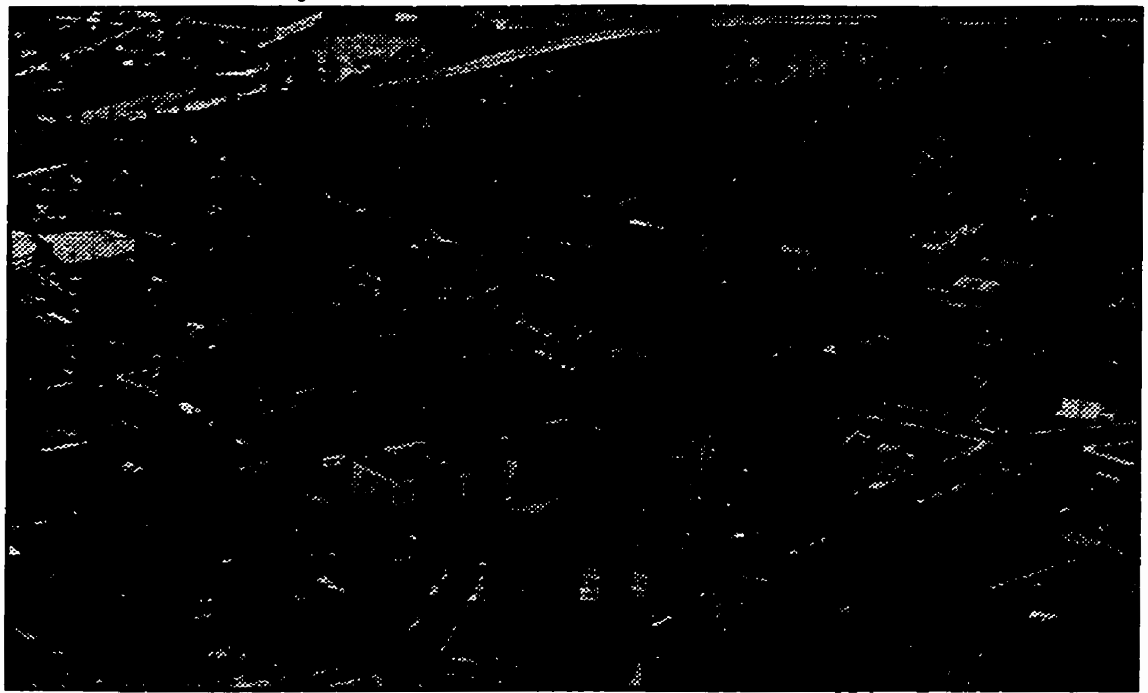
2.4 The ecology of the rooftop

Prinz, Prinz and Muhle (1981) in their article entitled "The biological activation of the urban structure" note "The city represents a desert in bio-climatic terms" (p.7). This is not a consequence of microclimatic conditions that offer no alternatives, this is the result of the inappropriate skin of our cities. Prinz et al. state,

> Seen biotechnically, every building in a city is an introverted monolith, and as such is conceived to repel all external advances from the outset, fully in the style of the earliest building cultures. Today it is primarily vibration, reflection, gasses and moisture which are repulsed into the spaces between the buildings and together these increase to form the well-known stress factors which cause living organisms to flee from our cities.
>
> (Prinz et al., 1981, p.26)

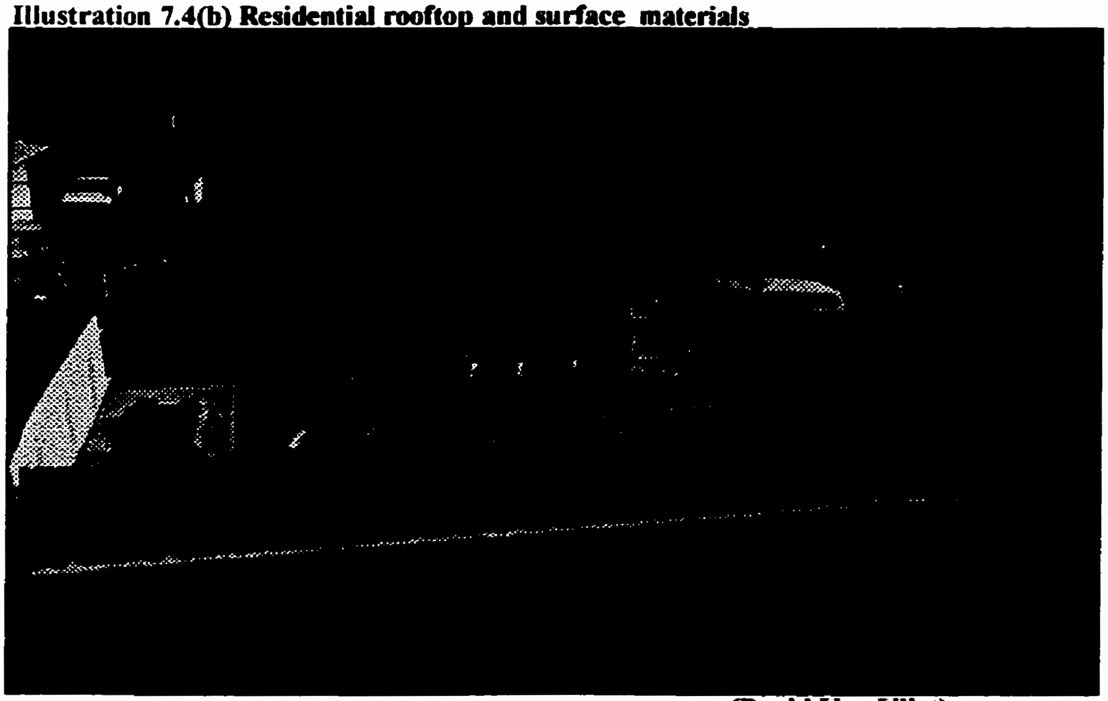
Prinz et al. believe that the objective of biological regeneration is to link buildings with the most appropriate forms of vegetation. The authors assert that low cost methods of roof planting have been achieved and that "a fully active biological epidermis with the help of vegetation, mass prior cultivation and assembly must be met" (p.26). Accordingly, the authors state that the biological activation of a large

Illustration 2.4(a) Rooftops ands surfaces of the Bronx, New York



(University of Manitoba Slide Library, 1974)

Illustration 7.4(b) Residential rooftop and surface materials



(David Van Vliet)

part of a city's epidermis, though not a panacea, could clearly add to the contribution of an ecological healing process (p.28).

The environment of the rooftop is significantly more extreme than that of the ground. These conditions must be understood prior to choosing the appropriate plants for a living roof. Reduced human disturbance and lower concentrations of some pollutants are positive factors associated with the rooftop environment (Johnston & Newton, 1991). During the design of a green roof, not only must regional variations in climate be considered, but the microclimate of the building must also be taken into consideration. Factors such as roof slope, aspect, and the presence of structures shading the rooftop are of great significance to green roof design.

At higher elevations, wind speeds tend to increase, the configuration of existing buildings surrounding the roof and the positioning of mechanical equipment on the roof may also cause increases in wind speed. In addition to high wind conditions that prevail over most roofs, high local suctions can develop with certain shapes of buildings or roofs (Tibbetts & Baker, 2000). Tibbets and Baker (2000) note that local suctions are most serious for a wind at an angle of 45° to the side of the building. Wind models have indicated that small areas of local uplift form up to five times the normal uplift at or near corners projecting into the wind. Sholtz-Barth (2001) notes that green roofs should weigh at least 15 lbs/sf. to withstand wind loads.

Wind can dry out the substrate of a green roof, cause erosion, and damage plants (Johnston & Newton, 1991). Solutions to these problems include, altering the configuration of structures to be built on adjacent sites, placing rooftop utility boxes so that they act as wind screens, or planting wind screens of hearty shrubs and hedges (Johnston & Newton, 1991).

Temperatures on a roof vary significantly from those at ground level. This is especially true for roofs that are not sheltered from the sun. Studies have shown that, during the winter months, soils located on the rooftop of buildings tend to be 5°C to 10°C warmer than soils located at land level (Johnston & Newton, 1991). This serves to aid rooftop plant growth (Johnston & Newton, 1991). The reverse of this has been observed in other studies. Kohler (1990) noted that thin soils on rooftops freeze more easily than deeper soils on the ground, while in the summer, rooftop soils remain an average of 5°C warmer (Johnston & Newton, 1991). Kohler also noted that temperature can vary tremendously across a single roof. It has been documented that air temperature remains 1-5°C warmer on the south side of roofs with slopes of 12 degrees or greater (Kohler).

The environment of the rooftop plays a significant role in the type of fauna that are able to inhabit extensive green roofs. In Essen Germany, ten green roofs (all between 3 and 5 years of age and 300-400 m^2) were studied in order to determine the relative diversity of plant and animal life on their surfaces. In addition to being close in age and in size, all of these roofs utilized local topsoil mixed with expanded clay granules as a substrate (Muller, 1989). Owing to the winter freeze of the substrate, fauna that burrows below the frost line in order to survive were not present on the roofs studied. Nevertheless, considerable numbers of microorganisms were present in all of the roofs studied. Organisms that prefer moist conditions were noticeably absent, as were temperature sensitive species such as earthworms. As a result, the breakdown of organic matter on these roofs was slow. Overall species diversity on the rooftop was much lower than that found on a meadow or comparable ruderal habitat.

Moisture is the most critical limiting factor for plants grown on green roofs (Thompson, 1998). Due to thin substrates and frequent fluctuations between saturation and drought, plants tolerant to a variety of moisture conditions must be selected. Indigenous plants tend to be the most suitable. Mixes of grasses, mosses, sedum, supervivum, festucas and irises have been used in the design of several existing roofs. As well, plants native to tundra, dry lands, and alpine slopes have been utilized (Khun, 1996). Substrates used must also take into account the root depth of each species. Even if the most suitable species have been selected, prolonged dry spells may necessitate some form of additional irrigation (Johnston & Newton, 1991).

2.5 Predominant flat roofing construction techniques

The term "flat roof" is used to denote a roof having a slope of up to 10°, while the term "low pitched" is used to denote the upper end of this range (Wolley & Skimms, 2000). Flat roofs are used on buildings where the designer has intentionally avoided traditional pitched roof design - or where they provide the only feasible option due to the irregular plan of a building.

There are two main types of flat roof construction techniques that are of particular relevance to extensive green roofing. These are the two-slab (internally aerated) technique and the one slab non-aerated construction technique.

2.5.1 Two-slab internally aerated roofs

This construction technique utilizes two slabs, the lower (fundamental) slab and the upper (roofing slab). In between these two slabs there is an air space. The thermal protection is performed externally by the upper slab and internally by the lower slab. The air in between the two slabs serves as insulation and reduces the temperature difference under the roofing slab and above the fundamental slab (Grozeva, 1997).

2.5.2 One-slab roofs

There are two different methods of single slab roof construction. In the first method, the condensation buffer is placed directly on the concrete roof surface. A layer of thermal insulation is then placed on top of the condensation barrier. Next, a waterproof membrane (usually bitumen, EPDM or PVC) is placed on top of the thermal insulation. Lastly, a layer of ballast (usually gravel) is placed on top of the waterproof membrane (Grozeva, 1997, p.22).

The one slab roofing method is commonly known as the "inverse roof". Using this technique, the waterproofing membrane is placed directly on top of the roof construction (as opposed to being placed on top of the thermal insulation layer). A layer of insulation is then placed on top of the waterproof roofing membrane. A filter mat is subsequently placed on top of the thermal insulation layer and a gravel ballast is then deposited on top of this filter layer. It is essential to the "inverse roof" that the thermal insulation layer is composed of a material that does not absorb water. Generally, glass fiber is used (Grozeva, 1997). The inverse system is beneficial in that the waterproof membrane, being placed below the insulation layer, is not subject to extreme fluctuations in temperature. Thus, the longevity of the membrane is increased.

2.6 Intensive and extensive green roofing systems

As briefly introduced in Chapter One of this thesis, extensive green roofs must be distinguished from intensive green roofs. In general, green roof development (whether intensive or extensive) involves the creation of green space on top of a human made structure. This green space can be above, below or at grade, but in all cases the plants are not planted in the ground (GRIM, 2000, p.3)

Intensive green roofs are characterized by their greater weight, higher capital costs and need for constant maintenance. Though more expensive, intensive green roofs are a useful means of providing city dwellers with an additional source of amenity space. The more traditional rooftop gardens, such as those constructed in Berlin, Germany, around 1900, had a weight of approximately 205 kg/m^2 (Scholtz-Barth, 2001). Given the advancements that have been made in structural systems technologies, newer extensive green roofs can weigh as much as 390 to 730 kg/m^2 (Scholtz-Barth), and soil depths can range from 20-60 cm (Peck, 1999). As a result of the substantial soil depth, the plant selection for intensive green roofs is not limited. Thus, trees, shrubs and groundcovers can be planted thereby increasing the ecological diversity of these rooftop environments (Peck, 1999). The maintenance requirements for intensive green roofs are both demanding and long-term.

In contrast, extensive green roofs are characterized by their low weight, minimal maintenance and low capital cost (Peck, 1999). The typical extensive green-roof growing medium is made up of a mineral-based mix of sand, crushed brick, leica, peat, organic matter and soil. For a standard extensive green roof the substrate depth can range from five to fifteen centimeters. The weight of a standard extensive green roof system ranges from 72.6 kg/m^2 to 169.4 kg/m^2. Peck (1999) notes;

> Due to the shallowness of the soil and extreme desert-like microclimate on many roofs, plants must be low and hardy, typically alpine dry-land or indigenous. Plants are watered and fertilized only until they are established and after the first year maintenance consists of two or three visits a year for weeding of invasive tree and shrub species, mowing, safety and membrane inspections. As a general rule, minimal technical expertise or practical experience is required for installation and maintenance.
>
> (Peck, 1999, p.13)

The relative advantages and disadvantages of intensive and extensive green roof systems are summarized in Table 2.6 on page 49.

There are additional classifications of green roofs that must be mentioned. These include semi-intensive green roof systems, and earth sheltered buildings. Semi-intensive systems use the same growth medium and plant types as extensive systems, weigh 125 to 1000 kg/m^2, and require slightly more maintenance than their lighter weight counterparts (Boivin & Challis, 1998). The earth sheltered type offers some similar design solutions and environmental benefits as green roofs, but are not technically considered green roofs. While there is a distinct height separation from the earth with green roofs, earth shelters form a continuous layer between the ground and the roof. The most similar feature between green roofs and earth-sheltered buildings is their energy-saving capabilities. Energy costs for earth shelters run approximately 40 to 70% less than those for equivalent aboveground structures (Johnston & Newton, 1991).

Green roofs are further classified as being accessible or non-accessible. Since accessible roofs are accessible to tenants and/or the general public, these roofs must adhere to building codes regarding live loads, access, lighting and safety. An inaccessible green roof is only accessed for maintenance purposes and periodic inspection. There are no requirements for the installation of safety features on inaccessible green roofs.

Table 2.6 The Advantages and Disadvantages of Extensive and Intensive Green Roofs

Intensive Green Roof *Deep soil, irrigation required, favorable growing conditions for plants*	**Extensive Green Roof** *Thin soil, little or no insulation, stressful conditions for plant growth*
Advantages • allows for greater diversity of plants • good insulation properties • visually attractive • can simulate conditions on the ground • allows for diverse utilization of the roof (food production, amenity space)	**Advantages** • lightweight, roof generally does not require any strengthening • suitable for large areas • suitable on roofs with a 0° to 30° slope • low maintenance • often no need for irrigation or drainage systems • relatively little technical expertise needed • often suitable for refurbishment projects • can leave vegetation to develop spontaneously • relatively inexpensive • look more natural • easier for planning authority to demand green roof as a condition of planning permission
Disadvantages • greater weight loading on roof • need for irrigation and drainage systems (use more energy) • higher costs • more complex systems and expertise required	**Disadvantages** • more limited choice of plants • usually no access for recreation etc. • unattractive to come, especially in winter

(Johnson & Newton, 1996, p.54)

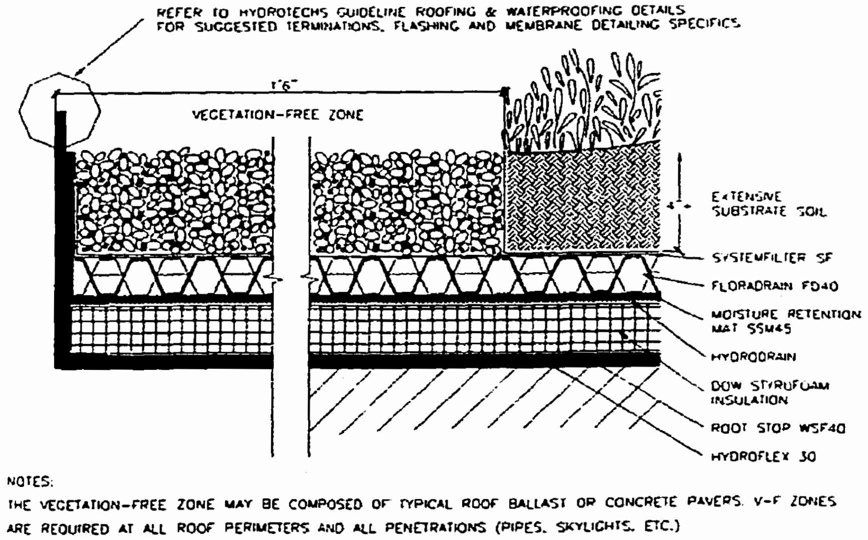
2.7 The design and construction of typical green roof systems

The functional layers of a standard extensive green roof are listed below in the order of their placement on top of the constructed roof surface. With new buildings, calculations should be made to ensure that the structure can withstand dead loads that take into account roof materials, insulation, waterproofing, vegetation and substrate in a saturated state (Johnston & Newton, 1991). With projects that involve the retrofit of a green roof onto an existing building, it is generally easiest to incorporate an extensive green roof with thin substrate. Such systems weigh little more than the original covering of gravel on top of bitumen (Johnson & Newton, 1991). Illustrations 2.7(a) and 2.7(b) on the following page show sections through two typical extensive green roof systems.

2.7.1 Roof membrane

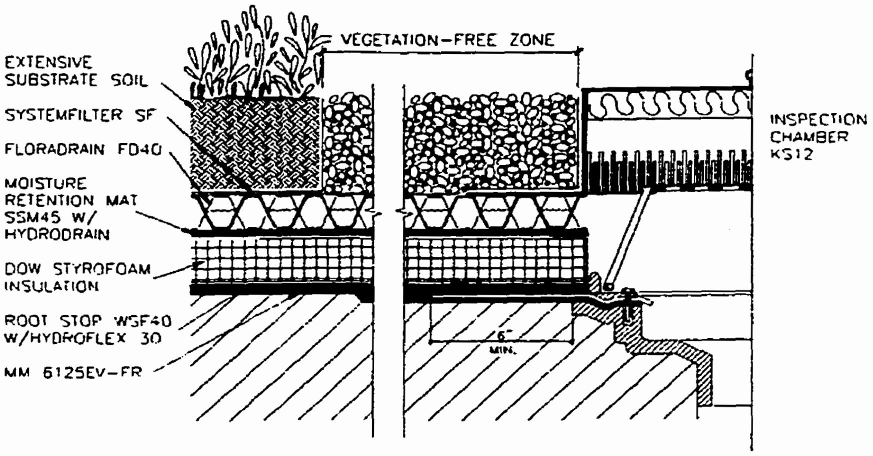
Unlike conventional roof systems, the waterproof membrane is the bottom layer of the standard green roof system. Scrivens notes that this layer should "be flexible, have good tensile strength, be easy and efficient to join and have relatively low adhesion to underlying materials (in Johnston & Newton, 1991). The traditional choice of waterproof membranes for flat roofs was between mastic asphalt and various grades of bitumen felts bonded with hot bitumen into a multi-layer membrane (Wolley & Kimmins). However, since asphalt is an organic product and thus a food source of microorganisms, these membranes must be covered with a high-density polyethylene (HDPE) membrane in order to prevent root penetration (Scholtz-Barth, 2001). Penningsfeld, Kurzmann, Kalthoff, and Fischer (1981) note, "there are enough

Illustration 2.7(a) Section through extensive green roof



(Hydrotech CadDetail, 2001)

Illustration 2.7(b) Extensive green roof with drainage outlet detail



(Hydrotech CadDetail, 2001)

examples of old roof gardens to demonstrate that normal waterproofing systems and even thick concrete slabs can be penetrated by aggressive rooting pioneer species" (p.639).

The extensive green roofing systems used in Europe most frequently use a polyvinyl chloride (PVC) waterproofing membrane. PVC membranes are noted for performing well at repelling water while also providing resistance to the penetration of roots (Scholtz-Barth, 2001). Quite often, PVC is used exclusively as a root protection layer (see below). Due to the significant environmental impacts of this material (a result of its use of carcinogens and powerful irritants in manufacture), as well as its limited recycling potential, PVC is not recommended (Wolley & Kimmins, 2000). Ludwig (1995), on the other hand, recommends the use of PVC over EPDM for its ease of recycling. Wolley and Kimmins assert that PVC may be easier to physically remove from the roofing surface than EPDM, however, the actual process of re-engineering the used product is much more difficult in the case of PVC.

EPDM (ethylene/propylene rubber), or hypolan CSPE (elastomeric synthetic) sheet material come with better ratings as environmentally benign products. They are easily reused and less carcinogenic than PVC. Tests have shown EPDM to be one of the most durable membranes over a broad range of temperatures. PVC showed slightly lower low-temperature durability (Wolley & Kimmins). The importance of low temperature membrane durability is critical to the climate of Manitoba. The only shortcoming of EPDM falls within the mechanical bonding process that must be used along its seams during installation. Because EPDM seams must be bonded with either adhesives or tape, a greater risk of leaking may result (Scholtz-Barth, 2001).

An additional roofing membrane that is suggested for use on extensive green roofs is TPO (thermoplastic polyfins). This product is noted as using an environmentally sensitive manufacturing process. In addition, US manufactures of this product have been adding bromide to the membrane in order to enhance its fire retardant capabilities (Scholtz-Barth). Unfortunately, it has been suggested that the addition of bromide to TPO may interfere in the long-term performance of the membrane (Scholtz-Barth).

Drefahl (1998) asserts that there are many good roofing membranes available on the market. He notes that the main reason for membrane failure is mechanical damage during installation. By installing temporary roofing during the construction and the green roof at the end of the building's construction, or by installing the membrane, drainage, and filter layers, thereby delaying roof planting until all other trades requiring access to the roof have completed there work; mechanical damage during construction and installation can be avoided (Drefahl, 1998).

Because standards in membrane construction have been achieved in laboratories rather than construction sites, Drefahl (1998) contends that the current European standards for roofing membranes used on green roofs are not high enough. To avoid membrane failure during installation Drefahl (1998, p. 5) provides six guidelines that should be followed.

1. Pay careful attention to manufacturers details. Temperature, wind and humidity conditions must be perfect when sealing membrane seams. If the roofing project is part of a critical timeline and the membrane is installed with little regard to installation conditions, the roof may fail.

2. Copper and aluminum sheeting should be avoided because of its difficulty in sealing.

3. Chemicals added to deter root penetration into bitumen roofing are sometimes added. Because of their toxicity and the threat these pose to the environment, these should be avoided.

4. Prior to installation, an expert should approve all planning and installation details. Standard details are not appropriate in green roof construction; roofs should be custom designed for each project.

5. All seams and joins along the waterproofing membrane should be tested for leakage prior to the installation of the upper layers. If testing by a qualified professional is done, the longevity of the rooftop can be guaranteed.

Valazquez (2001) notes that the correct application of a waterproofing membrane is essential to the long-term viability of the green roof. Although there is always the risk of leakage on any roof, there is at least one company in North America that offers a leak detection system. Roofscapes Inc. offers a European system of leak detection designed by AB Mess- und Trockungstechnik. Valasquez notes that this system can conduct water-tightness tests prior to the installation to the Roofscapes system and conduct annual surveys to verify that the waterproofing system is watertight below the vegetation layer. The system can quickly locate the source of any leaks.

2.7.2 Root protection and (optional) insulation layer

To protect against root penetration, structural movement, temperature changes and physical damage, a protective layer must cover waterproofing. In addition to this, if desired, an insulation layer can be added on top of the roofing membrane. A root protection barrier then covers this insulation layer.

Plant roots follow paths of moisture and have been known to perforate insulation that has become damp (McMarlin, 1997). If insulation absorbs only four percent moisture by volume, it can loose seventy percent of its thermal efficiency (McMarlin). Polystyrene board or cellular glass insulation with a sealed surface are noted as being suitable insulation materials. Because water is unable to accumulate in these products, the danger of root invasion is eliminated.

The materials commonly used for root protection include EPDM (1.5mm), PVC or a 5mm bitumen layer. Careful consideration must be taken when evaluating the type of root protection layer to be installed. If the plants to be used on the roof are particularly aggressive, the root protection barrier must be able to withstand strong rooting pressure. As with the roofing membrane, particular attention must be paid to the quality of the workmanship at all seam welds. In their four-year study of different types of roofing membranes Penningsfeld, Kurzmann, Kalthoff, and Fischer (1981) noted that "success is just as dependant on laying and fitting together of the membrane as it is on the quality of the membrane (p.644). In all membranes tested by Penningsfeld et al., root penetration occurred along welded seams as well as points of mechanical damage or stress which occurred during membrane installation (p.643).

2.7.3 Drainage layer

Roof drainage is provided by two methods. By pitching the roof slightly and incorporating a layer of granular material such as expanded clay aggregate or pea gravel, water is easily able to drain off the roof through this medium. A pre-fabricated drainage element can also be used. These hard plastic sheets, which have the appearance of upside-down egg cartons, act as reservoirs for water while allowing excess water to drain out once they are fully saturated. Some of these drainage mats are frequently used on surfaces such as highway overpasses and parking garage roofs. Some mats, especially those constructed from recycled tires, are extremely durable and can easily withstand being driven over by heavy mechanical equipment.

In installing the drainage layer, manufacturers note that it is important to do so on a cool day. If the surface temperature of the roof is too high, the drainage mat may stick to or soak up waterproofing from below. This will compromise the integrity of the waterproofing system. If this layer must be installed on a hot day, it should be covered with a substrate as quickly as possible (personal communication with J. Gessner, March 9, 1999).

The purpose of the drainage layer is to drain rainwater from the roof in order to protect the building's structural components from being damaged by the weight of accumulated water. The drainage layer can be made up of coarse materials such as broken ceramic particles, porous schist, gravel, or recycled rubber granules (Grozeva, 1997). Kolb and Schwartz (1986) recommend a 3cm layer of 2-6mm lava or 2-8mm clay granules capable of storing 30-40% of the water that falls on the roof.

2.7.4 Filter Layer

A filter layer is required in order to keep soil from infiltrating the drainage layer. This filter layer usually consists of a non-woven material such as polypropylene, polyethylene or glass fiber. On roofs with a slope of twenty degrees or more, a jute mat is placed over the substrate in order to prevent substrate erosion into the drainage system as the plants become established.

Drefahl (1998) remarks that fleece layers should always be placed over the drainage layer. Not only does this filter fabric prevent soil from seeping into the drainage system, but also acts to wick the water throughout the roof, thereby assuring that the water is evenly distributed throughout the roof surface and water loading is evenly distributed (Drefahl, 1998).

2.7.5 Substrate

A building's structural loading capacity often determines the type of substrate used. A typical extensive green roof should have a weight of approximately 15 lbs/sf (Sholtz-Barth, 2001). No single substrate is appropriate for all sites and environmental conditions. Although the ideal substrate for green roofs are considered to be thin and of poor quality, as vegetation dies back each winter and a layer of humus forms, nutrient and organic levels will begin to increase. Kolb and Schwatrz (1986) note that there is great difficulty in selecting the optimal sub-stratum for plant growth. The authors note that it is essential to choose a substrate that allows for the optimum growth of desired plant species while simultaneously deterring the growth of invading species that could compromise the integrity of the waterproof membrane.

A German study sighted by Kolb and Schwartz (1986) explored the maintenance requirements of fifty different substrate varieties. The study assumed that 8 minutes per year for each square meter of green roof would allow for adequate maintenance. Of the fifty varieties tested, five substrate mixes fell within this minimum maintenance requirement (while at the same time providing adequate plant growth of the desired species as well as the requisite water retention capabilities).

Kolb and Schwartz noted that, "It is to be expected that in substrata which greatly promote plant growth the growth of trees will likely be encouraged, thus requiring more care and attention" (p.7).

Early on in the development of extensive green roof systems, it was widely suggested that the water retention capacity of the substrate was the most important factor in extensive green roof design. However, Kolb and Schwartz (1986) advise that water retention is not as important as originally thought. Porous substrates can hold substantial amounts of water by volume but not for very long periods of time. Kolb and Schwartz note that during extreme rain events it is essential that water is able to flow through the substrate and into the drainage layer. Accordingly, a substrate that can hold 25-38% of its volume in water is considered sufficient. Substrates able to hold up to 80% water per volume have been tested, however, these did not bring about any major advantages in plant development (1986). Mehl and Werk (1987) concluded that the ideal substrate is composed of 60-70% pore volume, 30-40% firm substance, and should incorporates 35-45% water and 15-25% air (Johnston & Newton, 1991).

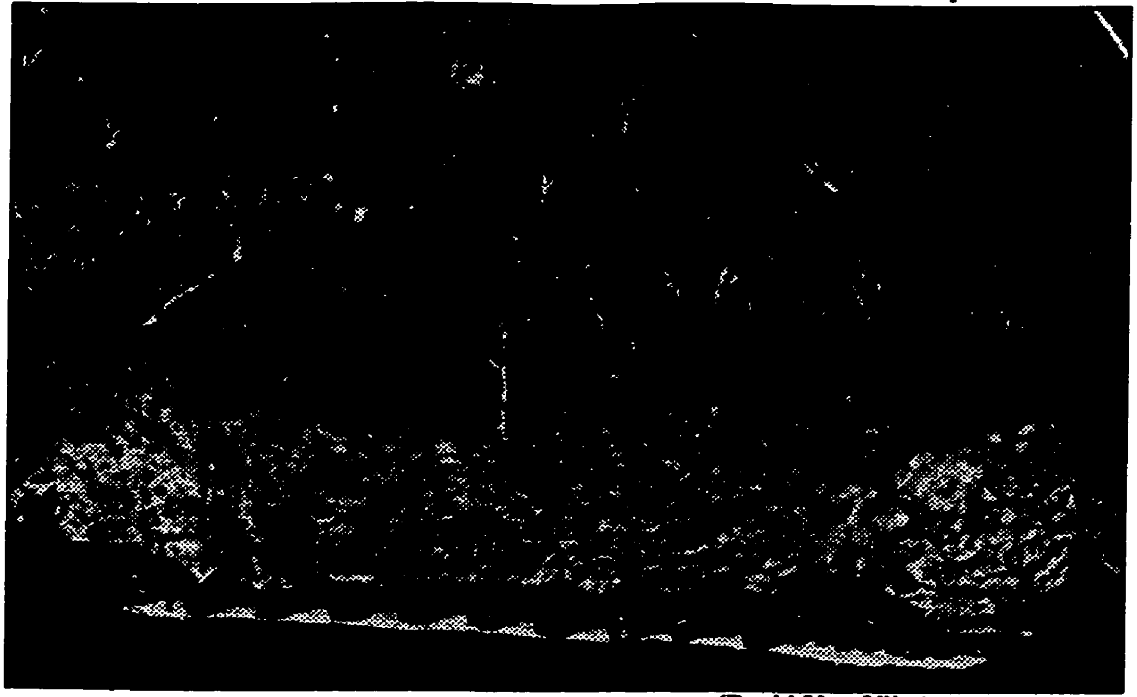
Scrivens (1999) suggests that any action that increases the air content and water retaining capacity of a soil is advantageous. Scrivens advocates the addition of organic matter such as coarse sphagnum peat. Kolb and Schwartz, however, state that substrates containing a high proportion of organic matter are subject to volume reductions resulting from mineralization. Kolb and Schwartz looked at five different substrate mixes and determined that all mixes showed a 20% loss in volume due to natural settling (1986 p.8).

Scholtz-Barth (2001) observed that the most effective substrate is made by stockpiling topsoil from the site prior to construction and mixing this soil with expanded clay or slate in order to increase water retention. Kolb and Schwartz (1986), on the other hand, do not recommend the use of locally available topsoil as it is often subject to sever infestation by weeds. Wolley and Kimmins (2000) recommend the use of materials such as sand and crushed gravel already on site to supplement the organic content of a substrate, "This enables the reuse of materials which would otherwise require disposal. So reducing transport costs, landfill requirements and production of new materials" (p.108).

The depth of the substrate is dependent on the loading capacity of the building, the type of plants that are to be grown, and the local climate. Boivin and Challis (1998) state, "the minimal thickness of 5 cm of growing medium used for extensive systems in Europe should be raised to 8cm in Northern regions in order to minimize winter damage" (p.38).

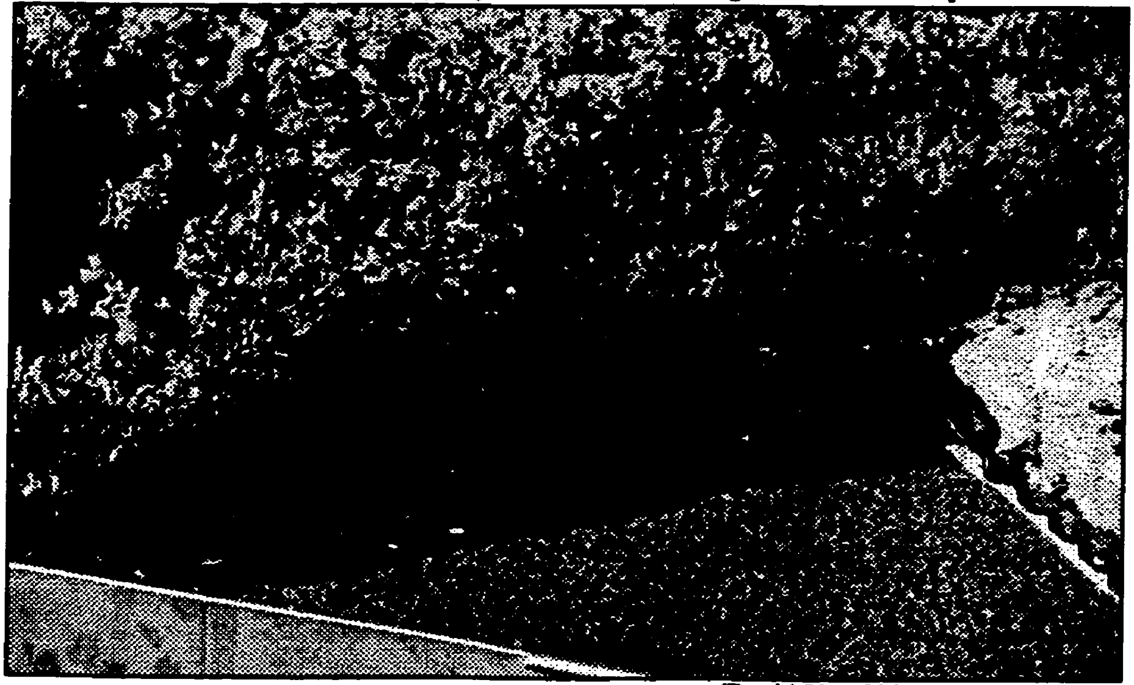
There also exist several less traditional substrate types that are currently being used on extensive green roofs. These include spent mushroom compost and sewer sludge - although the latter is not always recommended owing to the very high heavy metal content of some sludge (Wolley & Kimmins, 2000). In Berlin, a substrate made of pure sand is being used to support stonecrop. The sand is covered with a loose woven layer of hessian to prevent erosion. Within a few weeks of planting the stonecrop takes root and is entirely self-sustaining (Wolley & Kimmins). Some green roof systems include a form of rock wool as a lightweight alternative to soil. When dry, a rock wool growing medium is approximately 1% the weight of a standard

Illustration 2.7(c) Swedish Housing Exposition – Extensive green roof section photo



(David Van Vliet)

Illustration 2.7(d) Swedish Housing Exposition – Extensive green roof cutaway



(David Van Vliet)

extensive green roof substrate (Wolley & Kimmins). The manufacturer (Grodan) points out that this system is easy to install since it is laid out in mat form and is less prone to erosion. Unfortunately, rock wool is an extremely energy intensive product to manufacture. Once installed, rock wool requires a regular regime of fertilizers (Wolley & Kimmins).

2.7.6 Vegetation

Scrivens (1999) notes that plants have been growing in precarious locations ever since they began to evolve. Although we tend to place a great deal of mysticism around the notion of growing plants within a substrate that has been placed by man rather than nature, the "fundamental rules of horticulture do not change" (p. ii). Nevertheless, all plants require the same things if they are to grow well, namely, light, water, nutrients and mechanical support (Scrivens). Owing to the fact that plants are highly adaptable to the nutrient status of a soil, Scrivens notes that the importance of nutrients is of least importance to vegetation (p. ii).

Del Barrio (1997) states that plants used on green roofs should be selected for their ability to provide shade to the roof surface. Plants with large foliage development and/or with a horizontal leaf distribution should be selected (p. 191). By doing so, the transmission of solar radiation into the building envelope is decreased.

Scholtz-Barth (2001) and Scrivens (1999) recommend the use of native grass species. Native species sprout quickly and stabilize soil until slower growing plants are able to take root. The drought tolerance of native grasses is also noted by Scholtz-Barth as being beneficial to rooftop greening. Kolb and Schwartz (1989) note in their study of 150 plant species that drought tolerant native grasses adapted well to the extensive green roof environment. Scholtz-Barth noted that plant plugs establish themselves well on extensive green roofs, although grass seed or cuttings of plants such as sedum can be used, they take twice as long to become established. Plant cuttings have a survival rate of 50% while plugs have a survival rate of 80% (Scholtz-Barth). Table 2.7 indicates the characteristic common to plants that are suitable for use on green roofs.

Drefahl (1989) asserts that newly rooted plants and seed mixes work well on extensive green roofs. With early watering during germination, seed mixes and planted plugs adapt well to the growing conditions of the roof. Drefahl (1998) does not recommend the use of pre-grown mats. The author notes that these appear less adaptable to the effects of temperature extremes and require greater upkeep.

Of particular relevance to the development of green roofs in southern Manitoba, is the necessity to choose plants for extensive green roofs that are able to survive the acute periods of desiccation that our winters bring. The research completed by Penningsfeld, Kurzman, Kalthoff and Fischer (1981) noted that aggressively rooting plant species puncture roof membranes at a greater frequency than less aggressive plants. In this regard, the authors identified thistle as being exceptionally problematic. Penningsfeld et al. suggest that when the roots of aggressive species meet with resistance, they develop a stronger rooting pressure in order to counter such resistance (p. 644). A preliminary list of plants that would be suitable for green roofs in the Province of Manitoba is located in Appendix D.

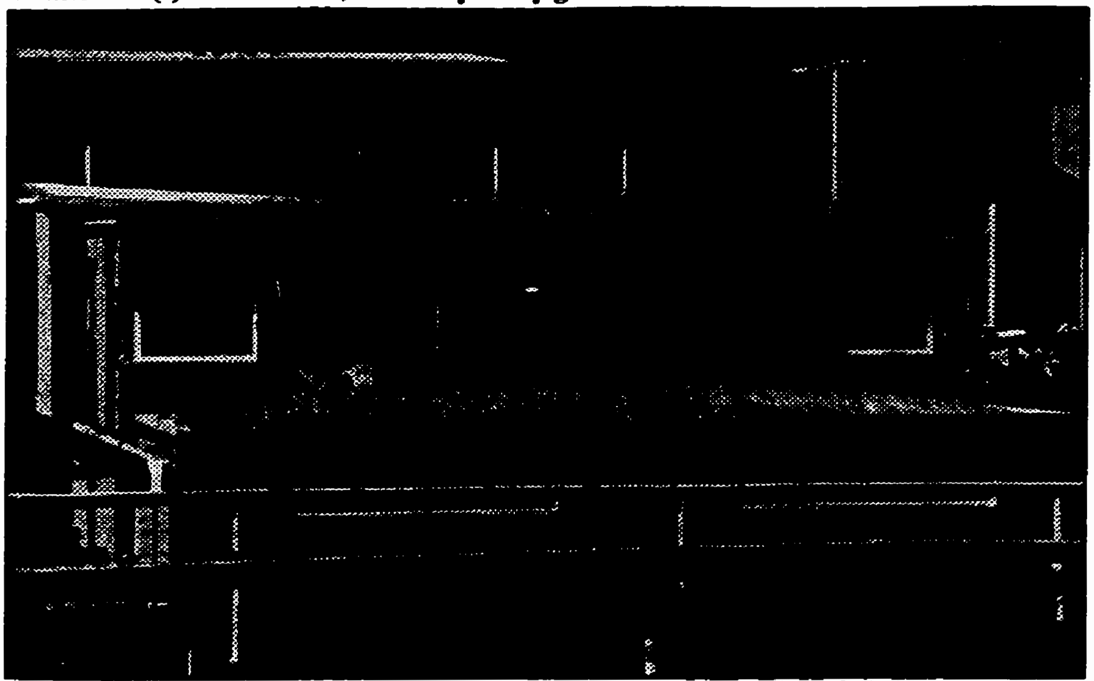
2.7.7 Fire prevention requirements

Grozeva (1997) notes that traditional green roofs were developed as a fire retardant measure against flying sparks. In order to be fire retardant, Vasella suggests that the roof substrate must be at least 3cm deep and have an organic content no greater than 29% (Grozeva, 1997). Ludwig (1995) notes that the organic content of a substrate should not exceed 20%. In maintaining such levels of organic content, a roof surface will provide adequate plant habitat while at the same time adding a layer of fire protection (Ludwig).

It is acknowledged by White (2001) that although saturated green roofs can slow down the spread of fire, unsaturated green roofs should raise concerns about their own combustibility. White points out that in Germany, green roof building codes require that lightning rods and stone pathways be placed as fire breaks every 40 meters on green roofed buildings. White asserts that fire hazards are a concern and that plants with a high water content such as sedums and supervivums be used in conjunction with native grasses (2001, p.9).

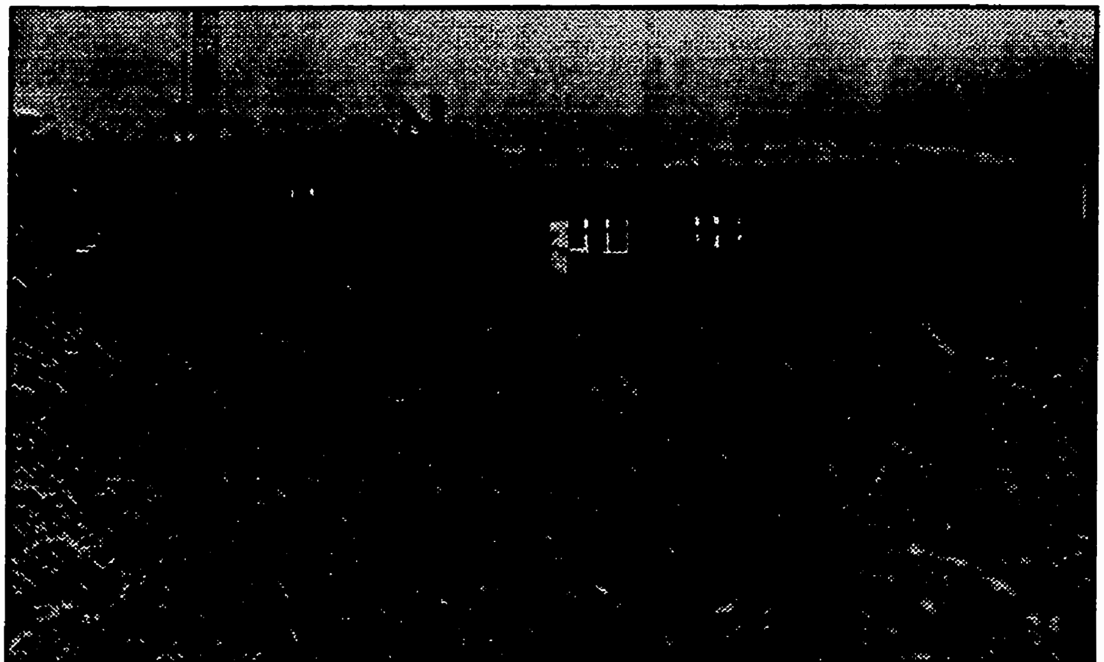
Roofs that are regularly irrigated require no special fire precautions. Extensive rooftop vegetation containing low plants such as sedum or moss are extremely resistant to fire and radiant heat (Grozeva, 1997). As a succulent, sedum stores a large volume of water within its leaf structure. As such, it provides excellent protection from fire (Grozeva). Due to the thin substrates found on extensive green roofs, grass species do not grow as tall as they would under natural conditions. As a result of this, the burnable mass of extensive rooftop plants is very small. Any fires that might occur would be very short in duration (Grozeva).

Illustration 2.7(e) Gelskirchen, Germany – Dry grasses on roof



(David Van Vliet)

Illustration 2.7(f) Kassell, Germany – Grass roof



(David Van Vliet)

Table 2.7 Choosing appropriate plants for extensive green roofs

Growth habit • Low-growing (60cm or less) • Establish a dense root layer • Capable of regenerating after periods of stress • Able to form resilient, permanent cover • Strongly rooted • Drought resistant characteristics, such as thick protection layers, a strong system of veins, and good water storage capacity • Some plants that will grow quickly are needed to help stabilize the soil	**Typical natural habitats** • Waste ground • Gravel and sand pits • Walls and other hard surfaces • Dry grassland • Open fields • Rocky outcrops
Cultivation • Tolerant of thin soils • Compete well in nutrient-poor soils • Prefer free-draining soils • Tolerant of drought • Survive periods of being waterlogged • Heat and sun tolerant	**Other Considerations** • Appropriate species will vary in accordance with the angle, position and height of the roof • Species should be tolerant of prevailing climatic conditions • Visually attractive with a wealth of blooms, good color and scent • Blend of low and taller plants, deciduous and evergreen • Predominance of native species for their value to wildlife • Maintenance free • Use of young plants, seed or turf depending on roof

(Johnson & Newton, 1996, p.60)

Drefahl (1998) observes that the drainage system and choice of substrate used on the roof play an important role in fire protection. Drefahl states that the substrate manufactures too often create porous substrates that are engineered with the specific purpose of detaining water. If such substrates are used, drought tolerant plants die off and are replaced with water-loving plants. In times of drought the water-loving plants dry out and become a fire hazard (Drefahl, 1998).

Although irrigation systems are costly, they can be used as a precaution against fire by ensuring that there is adequate soil moister. Drefahl (1998) notes that stone can be used as mulch on top of the growing medium. This serves to reduce plant stress due to drought by mitigating the moisture and substrate loss resulting from wind erosion and evaporation. By holding moisture in the substrate, mulches may also serve to protect against fire.

Vasella states several additional fire precautions that should be taken into account when designing extensive green roofs. These include the following:

- Smokestacks should be at a minimum distance of 40 meters from each other and a minimum of 30 centimeters above the roof surface.
- There should be a 50-centimeter wide gravel strip placed around all skylights and roof openings.
- Rooftops should have a 50-centimeter gravel buffer strip along any sides that are adjacent to other structures.

(Groseva, 1997, p.31)

2.8 Problems associated with extensive green roof construction

The technical problems associated with extensive green roof construction must not be overlooked. The living conditions of the rooftop are very harsh. This is further complicated by the loading restrictions that limit the weight, depth and composition of the substrate layer.

In the book entitled Roof Gardens: History, design and construction, Theodore Osmundson (1999) notes that most literature regarding roof gardens tends to focus on crowd pleasing features rather than the technical requirements of a long-lived roofing system. Failed systems, which are very costly to repair, tend to go unnoticed. Osmundson notes that most problems with intensive green roofing occur because of structural overloading, waterproof membrane failure, obstruction of drainage pipes, and the loss of soil and organic material (p.11). Villager (1986) notes that system failures occur when planting is done improperly, when inferior materials are used, or as a result of careless construction (p.2).

The durability of roofing membranes has been problematic. Scholtz-Barth (2001) notes that many of the buildings that employed green roofing in the 1970's did so as a response to rising energy costs. The membranes used at this time were of poor quality and have consequently required replacement. As a result of this experience, roofing membranes have become much more durable and long-lived. Nevertheless, Kolb and Schwartz (1986) note that, "care should be taken to insure that the root protection layer (and all subsequent layers) are chemically compatible. If the builder is unsure of the chemical incompatibility of membrane layers, a protective woven fabric should be provided between the roof drainage surface and the root barrier" (p.5). Through and experience and through small-scale prototype developments, many problems associated with roofing membranes are being eliminated.

The development of lightweight substrates has not been free of error. Krupka (1995) and Drefahl (1998) both warn that there has been a huge increase in the amount of single-layer substrate green roof systems currently sold by mail order firms. Unfortunately, the faults of these systems are abundant. The wind and water erosion of the substrate as well as substrate acidification results in poorly established vegetation. Krupka also notes that many lightweight substrates being sold contain disproportionate amounts of course granules such as clay and lava. The sun and the wind easily dry out such substrates. This drying of the substrate results in a lack of moisture and nutrients as well as the loss of seed (p.40). Kaiser (1981) notes that the use of peat as a main component of substrate can be very damaging. Peat decomposes rapidly. Thus, plant growth subsides until new organic matter is incorporated into the substrate. Kolb and Schwartz (1986) note that frost has a tendency of loosening up roof substrates through heaving and cracking. This action results in the exposure of plant roots and significant winterkill. The authors suggest that in order to prevent this, the clay content of the substrate should be increased, plants should be properly pressed into place when planted, and a mulch layer should be added to roofs affected by frost heave (p.8).

As a cost-saving method of green roofing, Drefahl also acknowledges that many of the early European green roofs used a "single-layer" green roofing technique. Using this method, there is no physical barrier placed between the roofing membrane and the substrate. Instead, a coarse substrate with fine particles mechanically removed was employed. This was done under the assumption that such a substrate would facilitate drainage while allowing plants to grow within it. It was found that the road vibration encountered during transportation to the site caused the larger "substrate drainage particles" to become deposited at the top of the admixture. When placed on the roof, the substrate continued to settle as fine particles shifted downward. Furthermore, repeated freezing fractured the coarse particles and reduced the pore volume of the substrate. Rather than an evenly mixed substrate with good drainage, the result was a substrate of fine lower particle and coarse upper particles that became increasingly homogeneous over time (Drefahl, 1998). Without a barrier between the substrate and the waterproofing membrane, fine particles block rooftop drainage outlets (Drefahl, 1998). The unintentional mechanical separation of the substrate during transport and the gradual settling and fractionalizing of the substrate creates a medium that does not adequately facilitate drainage (Drefahl, 1998). The resulting drainage problems have led to widespread plant loss and water saturated roofs that compromise the structural integrity of the building. Lastly, Drefahl (1998) asserts that without a physical layer between the substrate and the waterproofing membrane, friction and stress caused by ice easily damage the roofing membrane and lead to costly repairs.

Drefahl (1998) notes that some of the early materials used are now found to be chemically incompatible, and the ecological viability of some of the materials used is in question. The author also notes that suppliers and installers frequently experimented with green roofs in an effort to reduce costs, the substrates used (such as sewage sludge and crushed brick) are chemically and mechanically damaging, and improper plant/substrate selection has led to roofs that have become fire hazards.

Employed in the North American context, the benefits of extensive roof greening could be very significant. Nevertheless, North American designers must strive to learn from the extensive body of knowledge that the European green roofing industry has acquired in over 30 years of testing and use. Despite past successes, Drefahl (1998) notes that a crisis is emerging in the European green roofing industry. Because some systems were put in place before adequate testing was completed, some negative consequences of green roofing are being discovered.

In learning from our European counterparts, many problems that would otherwise go unnoticed until years from now can be uncovered. In conjunction with the German Chamber of Industry and Commerce and the Federal Ministry of Research, product standards, installation standards and professional accrediting bodies are being established in order to ensure the long-term viability of green roofing. The cost savings associated with ensuring that green roof manufacturers and installers are properly accredited must not be ignored.

Another problem that has been known to affect roofs located in regions that experience cold temperatures is that the seed mixes are not suitable for the extreme conditions. As a result, mesophilic forbes and grasses die out. This often leaves sedum as the sole survivor among patches of dying vegetation (Krupka, 1995). Whalley (1978) notes that poorly insulated buildings that experience heat loss create a condition whereby plant roots - normally frozen during the winter - are thawed by the escaping heat. If the temperature drops these roots become refrozen. This unnatural freeze/thaw cycle leads to additional winterkill.

By no means can it be assumed that after nearly 30 years of development, extensive roof greening is not without risk. The methods and materials employed have come a long way. However, given the inherent variability of climate and geography, these systems must be developed with a deep regard for local flora and fauna, climate, and materials.

2.9 Different types of extensive green roofs

There are several different types of vegetation mixes that are currently being used on extensive green roofs across northern Europe. The types described on the following pages are listed in order from the lightest to the heaviest. These categories do not presuppose that identical systems could be used in Manitoba. Rather, the following information is meant to inform the reader of the general sub-categories of extensive green roofs that have been developed in other parts of the world that are subject to climatic conditions similar, but generally more temperate, than the climate of southern Manitoba.

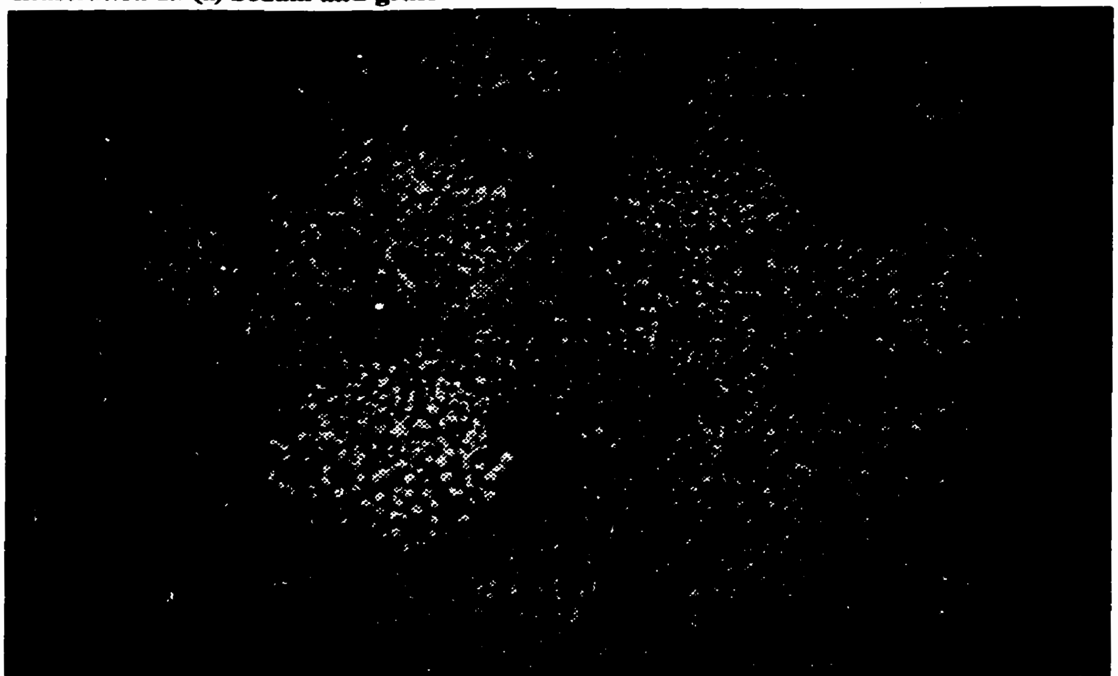
2.9.1 Moss-sedum

The moss-sedum vegetation mix is the thinnest and the lightest of the extensive system types. It is resilient to extreme growing conditions, its root systems are of minimal length, and much of the water is received directly through the leaves and blades of the vegetation. Although the plants may change color, the sedum-moss mix is able to withstand prolonged periods of drought. A moss-sedum mix requires a substrate layer of 2 to 8 cm thickness. When saturated, this type of system will weigh between 25 and 75 kg/m^2. Moss-sedum vegetation is rich in white and gold colors during the summer months. In periods of high humidity and low temperature, the moss may become a red-brown or yellowish color (Grozeva, 1997, p.31).

In Europe, thin moss-sedum vegetation (2-3 cm) is cultivated on a specially designed nylon and wire base which grows to form a pre-fabricated mat. This mat is transplanted directly onto the rooftop where the sedum species quickly cover the entire roof surface. In time, pockets of moss emerge.

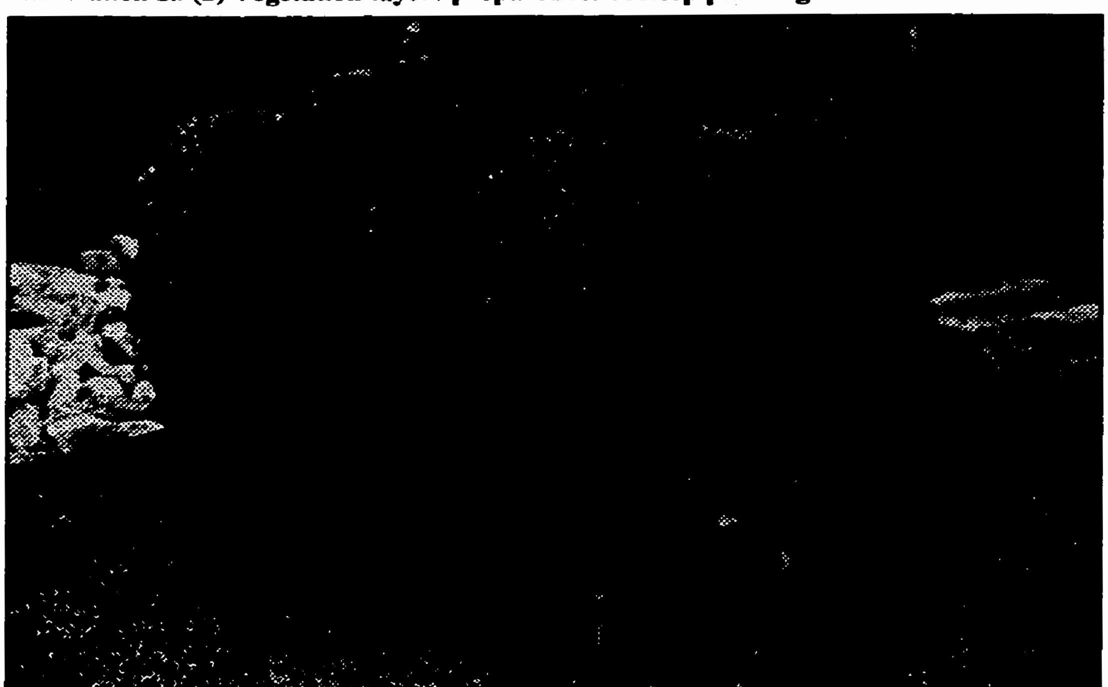
Grozeva notes that the origin of plant species utilized for extensive rooftop greening is particularly relevant to the geographic region in which the plants are to be grown. Grozeva states that plant stock taken from Germany and used in Sweden did not survive due to the extreme winter temperatures after transplant. The seemingly identical plant species, when obtained locally, were able to survive (1997, p.32).

Illustration 2.9(a) Sedum and grass roof surface



(David Van Vliet)

Illustration 2.9(b) Vegetation layers prepared for rooftop planting



(David Van Vliet)

2.9.2 Sedum

The sedum roof is the most shade resistant extensive green roof. However, this rooftop type requires a substrate that is capable of a greater amount of water than a moss-sedum roof. The total weight of a sedum roof is between 50 and 100 kg/m^2. A mat of sedum can be used on all types of roof surfaces (both flat as well as sloping). However, because sedum is unable to withstand prolonged periods of water saturation, a water drainage layer is essential on this type of extensive system (Grozeva, 1997).

2.9.3 Sedum-moss-herb

The sedum-moss-herb roof is suitable for sunny locations, shaded locations, and places of variable light. In rainy years, the mosses tend to slow down in growth and are replaced by herbs. The substrate thickness of this system is between 6 and 10 cm. The approximate weight of this extensive system is between 50 and 100 kg/m^2, roughly the same weight as the typical asphalt shingled roof (Grozeva, 1997, p.32).

2.9.4 Sedum-herb-grass

The sedum-herb-grass roof is suited to sunny as well as shaded roofs. It requires a substrate that is able to hold a large volume of water. Fully saturated, the sedum-herb roof weighs between 100-120 kg/m^2. The herb layer will generally take at least two growing seasons before becoming fully established.

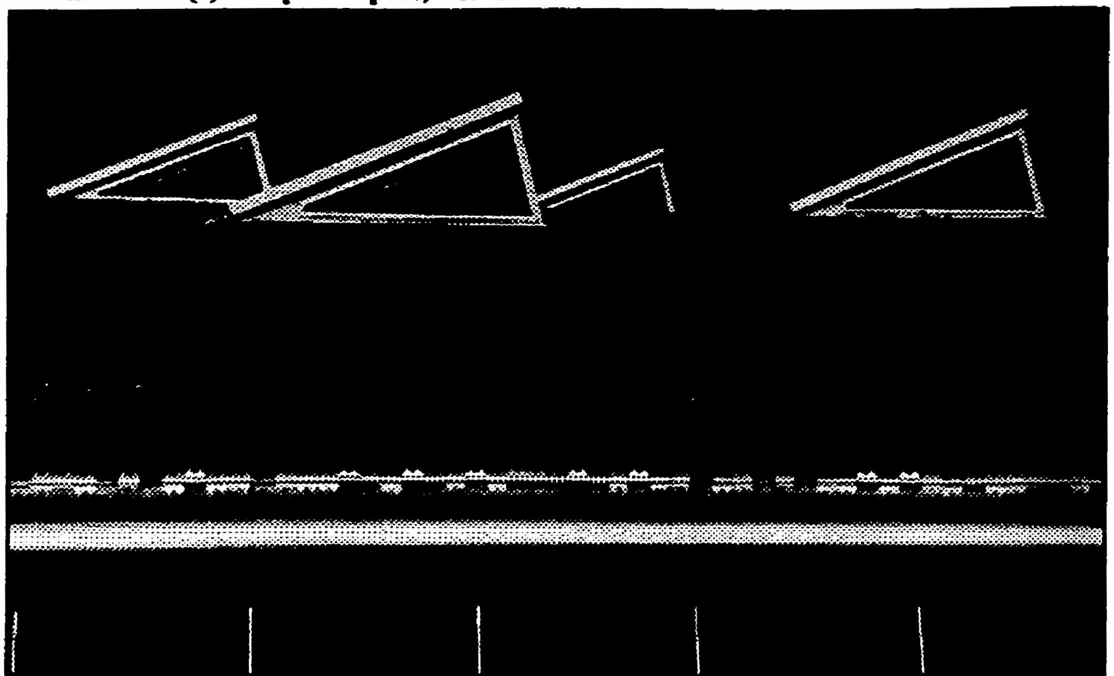
2.10 The costs and benefits of green roof construction

For the purpose of this discussion, the costs and benefits of living roofs are categorized into three groups. These groups include; benefits related to amenity, economic benefits and ecological benefits. It must be noted that many of the benefits discussed here, although important, are not necessarily expressed within the local marketplace. Although a dollar value cannot be placed on many of the benefits attributed to rooftop greening, these benefits must be itemized so that their breadth may be recognized.

2.10.1 Benefits and costs related to amenity

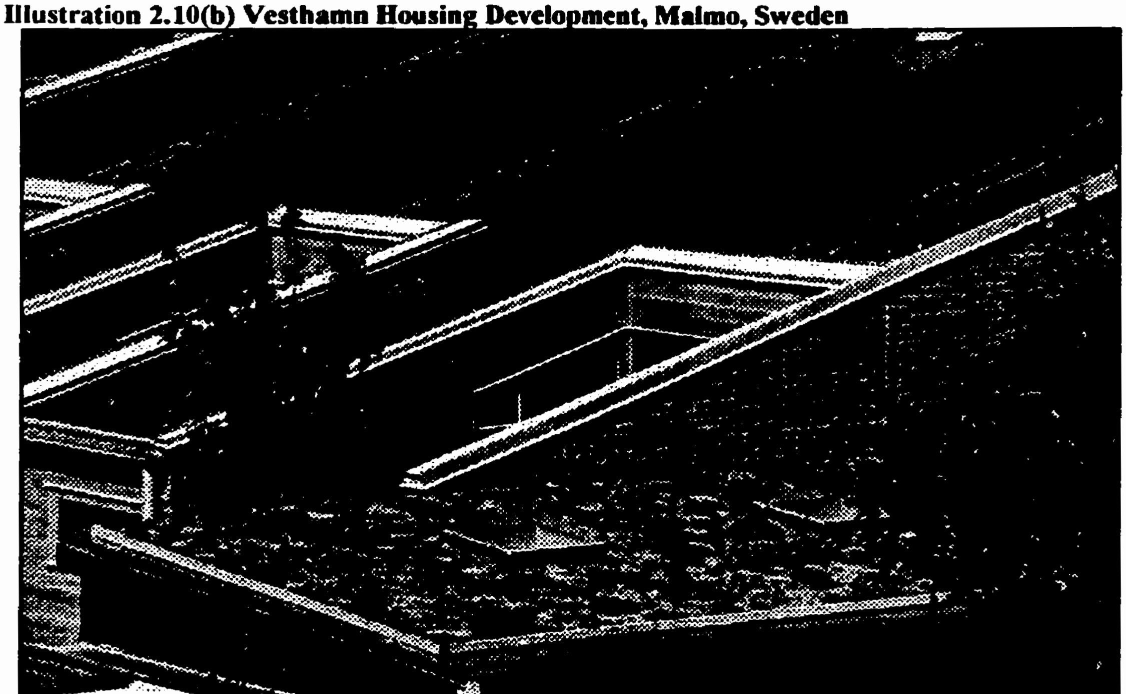
Johnston and Newton (1991) note four important amenities provided by living roofs. These include the psychological benefits of seeing greenery, the integration of the built form with the natural environment, the masking of unsightly rooftops, and the ability of living roofs to compliment building shape and form (p.47-50). Few costs (if any) are associated with the category of amenity. Nevertheless, the visual appeal of these roof systems should not be considered universal. Thus far, research has shown that the amenity provided by living roofs tends to be speculative. Alexander (1977) notes that since the 1930s, flat roofs have become architectural fads rather than useful places. As such, these roofs do not meet our psychological needs. Alexander suggests that if a roof is hidden, its presence will not be felt. As a result, people will lack a fundamental sense of shelter (p. 577).

Illustration 2.10(a) Schipol Airport, Netherlands



(David Van Vliet)

Illustration 2.10(b) Vesthamn Housing Development, Malmo, Sweden



(David Van Vliet)

2.10.2 Economic benefits and costs

Many economic benefits can be attributed to the use of extensive green roofs. With the introduction of mechanical air-conditioning systems, there has been little emphasis placed on natural cooling. Del Barrio's analysis of the cooling potential of green roofs (1997) concluded that green roofs act as insulating devices rather than cooling ones. Heating and cooling costs may be significantly lower in buildings that employ green roof systems. Both substrate and plant layers perform as insulation, keeping the building warmer in the winter and cooler in the summer (Kuhn, 1996).

Scholtz-Barth (2001) notes that the average extensive green roof adds 25% insulation when dry. A wet roof, according to Scholtz-Barth, is of little insulation value. Del Barrio (1997) states that light substrates are able to hold more water, reduce thermal conductivity through the building envelope and increase thermal efficiency.

With a cushion of warm air captured in the grasses and plants of a green roof, a building can retain heat that would otherwise be removed by wind (Kuhn, 1996). The surface texture of extensive green roofs creates friction (Scholtz-Barth, 2001). This friction decreases wind-speed at roof level and reduces heat loss resulting from the convective properties of the wind by 50%. Gotze (1988) concluded that, on average, green roofs were ten percent more energy efficient than conventional roof systems (Johnston & Newton, 1991). Kaiser (1981), found that in summer, the average room temperature below a conventional roof was calculated to be 30° C. As an indication of their ability to reduce interior room temperatures during summer, the average room temperature below a living roof placed under the same conditions was

26°C (Johnston & Newton, 1991). The National Research Council is currently conducting research into the energy efficiency of green roofed buildings (GRIM, 2000).

Green roofs have been shown to increase the life span of roofing membrane by protecting it from UV rays, wind, hail and extreme fluctuations in temperature (McMarlin, 1997). Bitumen and asphalt surfaces heat up much faster than planted surfaces. Some studies have shown that the exposed area of a black roof can reach up to 80°C. An equivalent area of planted roof reaches 27°C (Johnston & Newton, 1997). Kohler and Baier (1989) conclude that aggregate covered bitumen roofs will remain an average of 3°C hotter than green roofs throughout the span of a summer (Johnston & Newton, 1991). Kaiser (1981) noted that in the summer, the difference in temperature between a green roof and an asphalt roof is as great as 21°C.

In winter, the erosion of roof bitumen and the fracture of roofing surfaces by frost formation can be reduced through the use of living roof systems (Johnston & Newton, 1991). Kolb, Schwartz and Trunk (1983) noted that the average winter surface temperature of gravel roofs in Germany was -12°C, planted roofs under the same conditions had an average surface temperature of -5°C (Johnston & Newton, 1991).

Khun (1996) notes that green roofs serve to protect roofing membrane from puncture and from the damage resulting from foot traffic and maintenance. Scrivens (1980) noted that an example of exceptional green roof durability is found on the Kensington and High Street Building in London. Installed in 1938, the membrane materials were examined fifty years later and found to be in excellent condition

(Johnston & Newton, 1991). In contrast, the life span of the average flat roof ranges between ten and fifteen years (Johnston & Newton, 1991). Kolb and Schwartz note that green roofs markedly reduced the temperature fluctuations that have frequently been observed on asphalt covered roofs. Kwik (2000) explains that a green roof can double the life expectancy of roofing membranes by shielding them from UV radiation and temperature fluctuations. Scholtz-Barth (2001) estimate that recently constructed green roofs will last three times longer than conventional roofing. Tibbets and Baker assert that roof membranes can be damaged by airborne waste products from industrial as well as domestic furnaces and industrial process equipment (2000). Heavy dews are common on roof surfaces and pollutants deposited on roofs may form acids that can damage metal flashing, organic felts and roofing membrane (Tibbets & Baker, 2000). As plants are able to filter and incorporate pollutants, green roofs may serve to mitigate the corrosive effects of airborne pollutants on roof surfaces and membranes and extend the life span of the roof.

Drefahl (1998) sites a study commissioned by a Berlin housing group which compared the longevity and costs related to green roofs and standard roofing systems. The study found that the Bitumen roofs lasted an average of 9 to 18 years, add to this the cost of rent reductions due to leakage, law suits, employment costs and water damage compensation; the real costs of standard roofing systems ballooned. Seventeen and eighteen year old green roofs were inspected and found to be basically new and had virtually no maintenance costs associated with them.

In essence, living roofs consist of additional layers placed directly on top of conventional roof systems. As such their higher installation costs should be offset by their greater durability. However, if the proper species mix and substrate type is not chosen for the site conditions, high maintenance costs can result (Thompson, 1998). Appropriate species selection and accurate system design should serve to decrease the maintenance costs of green roofs over the long run. Indeed, within the Manitoba context, this is a very important consideration.

By adding to a building's functional green-space, some living roofs could reduce the costs associated with acquiring additional land for this purpose. Green roofs may also be attractive to planning authorities and provide an added incentive to those looking to purchase or lease property. Though difficult to quantify, green roofs attract the public eye and result in a positive image for those organizations that employ this technology (Johnston & Newton, 1991).

The high cost of installing an extensive green roof is prohibitive to those interested in employing this technology. The added cost of plants, substrate and drainage greatly increase the cost of this type of roofing. In addition, a newly planted roof must be watered regularly as the plants become established. Very large extensive green roofs often require drip irrigation. Drip irrigation systems are recommended because they provide water directly to plant roots while allowing the soil surface to remain dry and resistant to weed infestation. Unfortunately, the added cost of drip irrigation is substantial. The additional cost of occasional weeding and biannual fertilization (to prevent soil acidification) may also need to be factored into the maintenance costs associated with green roofs (Scholtz-Barth, 2001).

In Europe, where the demand for extensive roof greening is much greater than in North America, many innovations have led to reduced installation costs. For example Scholts-Barth notes that in Germany, vacuum trucks blow substrate into place on the roof surface while pre-grown vegetation mats are rolled out over the substrate. As demand begins to increase Scholtz-Barth predicts the cost of extensive green roof installation in North American markets to drop by 40%.

If extensive roof greening is to become widely accepted within North America, we must change the way we maintain the roof surfaces of our building stock. Once a standard roofing system is installed, roof inspections tend to be minimal. As the roof begins to leak, stopgap measures are taken to repair the leaking. As leaking increases, the entire system must be replaced. Extensive green roofs require annual inspections and a greater amount of attention than standard roofs. However, these costs are recouped over the long run as the durability of extensive green roof systems lead to cost savings in the long term.

2.10.3 Benefits and costs related to urban ecological health

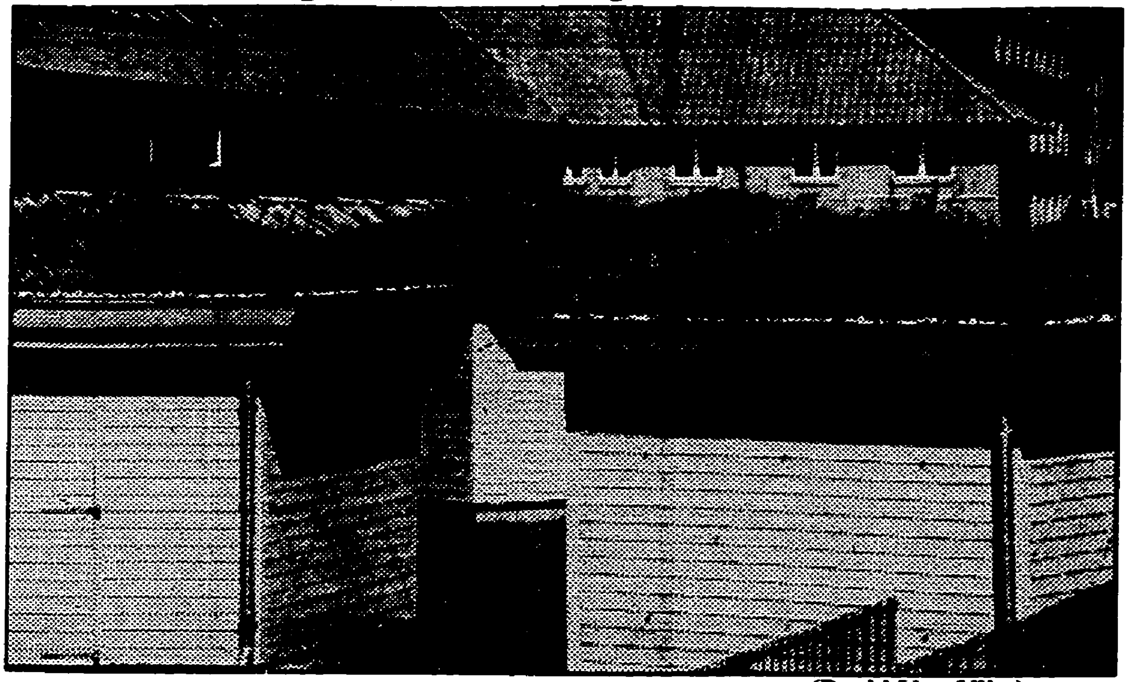
Many ecological benefits are associated with living roof systems. However, the majority of these benefits have not been thoroughly investigated. Most studies in urban ecology tend to be land-based rather than focused on the ecology of the built form. Michael Hough (1990) writes,

> Vast tracts of urban land overwhelm public open space in area but which, for the most part, lie idle and unproductive. A major shift is needed...whereby urban open space is seen to perform productive and environmental functions in addition to its traditional and aesthetic functions.
>
> (Hough, 1990, p. 10)

Hough's arguments are equally relevant regarding the urban rooftop environment. Not only should the landscape of the roof serve the traditional function of providing shelter, it should also function as a living entity within a larger ecological context. In order to validate living roofs as a viable alternative to conventional roofing, ecological studies specific to the rooftop environment need to be undertaken. By looking at land-based studies, one can only gain insight into the probable benefits of green roofs.

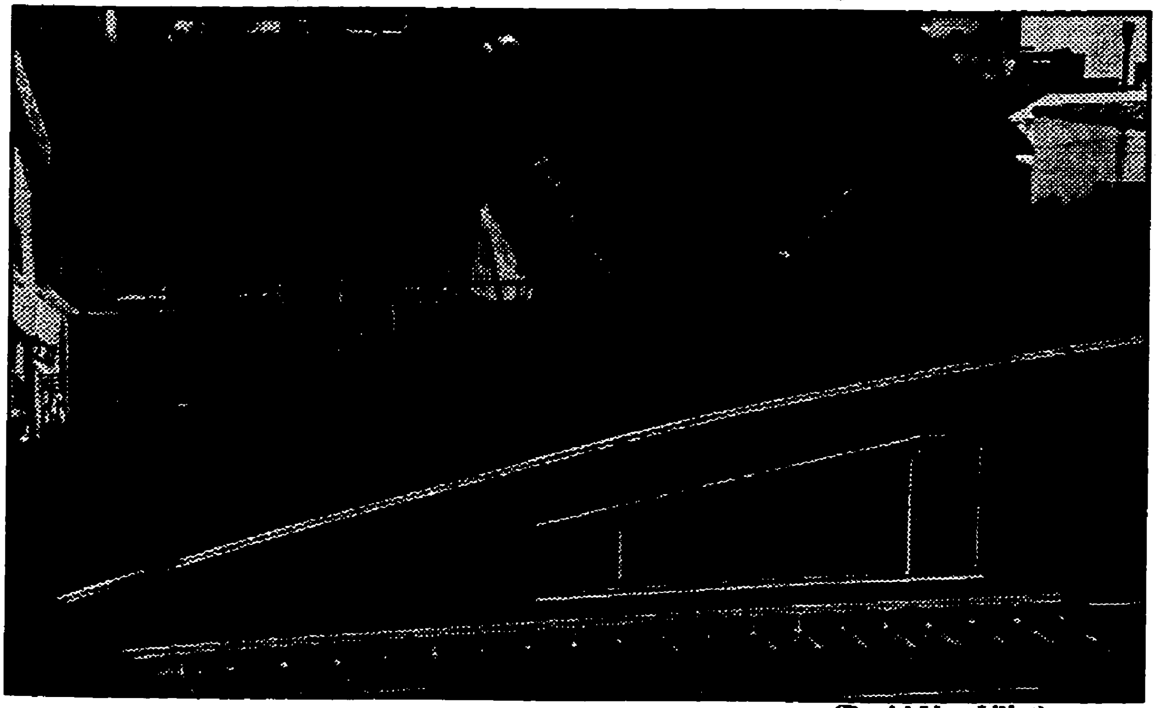
Land-based studies have shown that one hundred and fifty square meters of plant surface area (the area of the roof multiplied by the height of the plant multiplied by the surface area of the leaves and stem) produces enough oxygen for one person for twenty-four hours (Kuhn, 1996). In addition to this, plants also serve to filter out air-borne particulate matter (such as sulfur dioxide and hydrocarbons) and thereby clean the surrounding air. Scholtz-Barth notes that the amount of dust found in non-vegetated urban areas was in the range of 10,000 to 20,000 particles per liter of air. Vegetated urban areas, on the other hand, contained 1,000 to 3,000 particles per liter of air.

Due to their inherent discontinuity, green roofs are not a true substitute for ground-level wildlife habitat. Nevertheless, many birds and insects will find suitable food and shelter on a green roof. The most attractive green roofs for wildlife are those that provide fauna with the basic needs of food, shelter, and water. Even if all of these requirements cannot be met, living roofs could still provide important links in an urban network of green-spaces particularly for avian species (Johnston & Newton, 1993). Schubert and Huber (1995) note that the development of the La Roche industrial park (adjacent to the Rhine River in Kaiseraugust, Germany) is an excellent model of ecological planning and design. In addition to maintaining existing biotopes, Illustration 2.10(c) Mollegarden, Denmark – Storage sheds



(David Van Vliet)

Illustration 2.10(d) Vesthamn, Malmo Sweden – Residential housing



(David Van Vliet)

ruderal fields, and migration corridors for local animals, one third of all roof area utilized green roofing. The total roof area covered by verdure on the Kaiseragust site is approximately 43,000 m^2. The authors note this industrial park has been successful in maintaining species diversity and population numbers.

If provided with an adequate source of nectar, insects such as bees and butterflies become attracted to living roofs. Johnston and Newton (1993) note that butterflies will visit green roofs as high as twenty stories. The substrate in the soil of a living roof will provide a home to earthworms, spiders, beetles and a host of other insects (Johnston & Newton, 1993). The habitat provided by extensive green roofs is subject to less human disturbance than ground level habitat. This is an important factor for those bird and insect species that are sensitive to human disturbance.

The urban heat island effect is a phenomenon common to all cities caused by several factors. Surface materials such as concrete, brick, tar and asphalt used within the typical urban environment absorb heat more quickly and store it in greater quantities than the plants, soil and water of the surrounding countryside. Owing to the high concentration of fossil fuels burned in cities, heat inversions that trap warm air above and further heats urban environments. Plants and water also absorb heat energy, this energy is expended through evapotranspiration. This results in heat loss rather than heat gain (Spirn, 1984). By increasing the amount of biomass within the urban environment, incoming radiant energy that heats our cities would be reflected rather than absorbed and re-released. This would lower the effects of the urban heat island and result in less fluctuation between daytime and nighttime temperatures.

The heat island effect may be both beneficial and harmful to our urban environment. In the winter, the urban heat island may decrease the amount of energy required to heat our building stock. While in the summer, the heat island effect results in higher expenditures associated with cooling our building stock. A study of twelve cities in various regions of the United States indicated that heating was required on 8 percent fewer days in the city when compared to rural regions. Conversely, in urban areas, air conditioning was required on 12 percent more days (Spirn, 1984, p.55). In noting that increased urban temperatures have a negative effect on urban air quality and urban ozone levels, Kwik (2000) refutes that the heat island effect provides urban dwellers with any positive repercussions (p.16).

As a result of the by-products of mechanization and the high concentration of heat-absorbing materials in urban areas, the ecological health of our urban environments would likely benefit from the widespread use of green roof systems. Studies attempting to measure the magnitude of the benefits provided by increasing the amount of plant biomass within urban centers are currently underway (GRIM, 2000).

Green roofs have been noted to dampen ambient urban noise by up to 3dB and attenuate the sound entering buildings from external sources by up to 8dB (ZinCo Planning Guide, 1997). Other studies have concluded that, with a thick substrate, noise reductions of up to 50dB can be realized (McMarlin, 1997). In buildings which are particularly sensitive to the effects of noise (such as hospitals), green roofs could be used as a means of creating a more comfortable environment. Likewise, in areas which are subject to high levels of noise from above (such as air traffic), green roofs could be used as an effective means of attenuating sound.

Research into the manufacture of living roof systems has indicated that the membranes and filter mats often utilize recycled materials. The drainage systems and root barriers use recycled plastics, while the roof substrates often use high quality compost and recycled mineral material such as clay brick and breeze block. Living roof systems offer an outlet for the use of recycled materials as well as an incentive to begin recycling materials such as organic waste. The longevity of living roof systems would clearly lead to a reduction in the amount of roofing waste being deposited in our landfills.

Lastly, it must be noted that one of the greatest benefits of employing extensive green roof systems is their ability to filter rainwater as well as hold rainwater so that it can be slowly evaporated into the air rather than being immediately shed into storm sewers or other stormwater infrastructure. Section 2.11(below), explores in greater detail the benefits of green roofs as an alternative means of stormwater management.

2.11 The role of green roofs in the management of stormwater

The wide-scale use of living roofs might serve to reduce the specified size of catchment zones and storm-water drainage pipes. This would result in cost savings related to infrastructure. As is done in several German municipalities, the savings realized through the installation of less costly sub-grade infrastructure could be reallocated to offset the cost of green roof installation.

As has been noted by the Green Roofs for Healthy Cities Coalition (GRHCC), a high percentage of urban land is dedicated to buildings. As a result, the management of stormwater through the use of alternative surface treatments at grade would be negligible. In such cases, utilizing the building's roof surface would serve as a better solution (Kuhn, 1999).

In 1999, six independent consulting companies conducted a preliminary study regarding the cost effectiveness of green roofs in the Toronto area. The study entitled Demonstration of Non-Structural Stormwater Management Practices used data gathered from Soprema roofing systems and the City of Toronto Department of Works and the Environment. The report compared the costs of installing a standard green roof versus the cost of installing additional infrastructure as a means to mitigate stormwater runoff. Assuming a standard-roof live load of 195kg/m^2, an 85% water retention rate and a ten-year life cycle, it would cost \$24.26 per m^3 of water per year of runoff to manage stormwater using a green roof. Using the same ten-year life cycle and live load capacity, the cost of installing an underground stormwater storage tank was calculated to be \$58.80 per m^3 of water per year (Kuhn, 1999).

Scholtz-Barth (2001) states that in any areas left altered by impermeable surfacing materials, 30% of all rainwater runs to shallow aquifers that feed plants, 30% runs deeper into lower aquifers, and 40% is returned to the atmosphere through plant evaporation (p.3). Surface water runoff from unaltered sites is miniscule.

In urban areas with 75% hard surfacing, 5% of the storm runoff flows into shallow aquifers, 5% of the runoff reaches the deeper aquifers and 15% of the rainfall is evaporated by plants. The remaining 75% becomes surface runoff draining (often untreated), into rivers, streams and other water bodies.

A highly beneficial action performed by green roofs is their capacity to retain rainwater rather than divert it into the stormwater sewage system. According to information obtained from an industry representative, living roofs are able to retain 70 to 90 percent of the moisture that falls on them during the summer months (ZinCo Planning Guide, 1997) and 40-50 percent of the moisture that falls on them in the winter (GRHCC, 1999). The capacity of a green roof to retain water is highly dependant on regional climatic conditions, the type and depth of the substrate, the plants used on the roof, and the slope and aspect of the roof (Grozeva, 1997). Grozeva notes that the water saturation time for one square meter of green roof can vary between a few minutes and several hours. Once the vegetation and substrate are saturated, the increment of effectiveness of the system in retaining additional moisture is negligible. Scholtz-Barth (2001) notes that if the slope of a green roof is too steep, the benefits of stormwater retention will be lost.

Tom Liptan ASLA, a storm-water specialist from Portland's Bureau of Environmental Services, preformed an informal study regarding the effectiveness of green roofs as a means of absorbing rainfall. Liptan used the roof of his flat ten-by-eighteen-foot garage as a test site. Using a mix of compost and topsoil as a substrate, Liptan planted a variety of sedum and allowed volunteer grasses and other species to take root. In the first rainfall, out of approximately forty gallons of rainwater that landed on the roof, only three gallons reached the ground (Thompson, 1998).

Depending on duration, intensity, and saturation, Liptan noted that his roof held anywhere from fifteen to ninety percent of the water that fell on it.

Kohler (1989) conducted a more formal study on green roof systems in the city of Berlin. This study concluded that seventy-five percent of the precipitation which fell on these green roofs was absorbed by the roof system. This consequently served to reduce discharge to twenty-five percent of the normal levels. By using extensive green roofs, stormwater is released into the supporting infrastructure once the peak loading on the system has diminished. By slowing the release of runoff, additional benefits of green roof systems accrue.

It is noted in the Green Roof Infrastructure Monitor (2000) that a wide range of hydrologic responses can be achieved by varying the design of the green roof. The saturated infiltration capacity, porosity, and matric potential/moisture content relationship of the substrate can be altered in order to achieve the desired response (i.e. the relationship between how porous a soil is and the amount of water it can hold). In addition, the transmissivity and the spacing of relief drains can also be altered in order to obtain the desired hydrologic response (p.7).

The widespread use of green roofs would likely have a positive effect on the water quality of our rivers and streams. Preliminary studies have shown that there is significant potential for retaining and evaporating water on site during rain events of both short duration and high intensity, as well as rain events that are long in duration and low in intensity. Many Canadian cities have antiquated combined-sewer systems in their older districts and neighborhoods. Combined sewers collect sewage waste from commercial, residential and industrial areas as well as rainwater. During heavy rain events, if wastewater treatment plants are unable to handle the loading placed on them, the wastewater from combined sewers is diverted away from stormwater management facilities and into local rivers and streams. It is quite possible that with enough roof area being covered by green roofs, the frequency of combined sewer overflows would decrease (Kuhn, 1996). In addition to enhancing the quality of our rivers and streams, the widespread application of green roofs could also serve to decrease our dependence on costly infrastructure such as sewage treatment plants.

A report published by the Green Roofs for Healthy Cities Coalition (1999), and the Green Roof Infrastructure Monitor (2000), list the problems that result from excessive stormwater runoff. These are summarized below.

- Heating and contamination of stormwater runoff
- Drop in local water tables
- A drop in stream/base flow during dry weather
- Increased frequency and intensity of flooding
- Degradation of aquatic habitat
- Damage to fisheries
- Stream bank erosion and the build-up of contaminated sediment
- The degradation of stream bank appearance
- Loss of recreational use of water bodies
- Loss of tourism
- Increase in the frequency of combined-sewer overflows

The list of consequences of urban development exists largely because of an outdated paradigm. As much as possible, we must rethink infrastructure so that it mimics the natural processes of nature as best as possible. Rather than placing nature in underground conduits, we must rethink the surfaces of our cities. Chapters Four and Five will take a closer look at the role that extensive green roofs might play as an alternative means of non-structural stormwater management in the City of Winnipeg.

2.12 Chapter summary

The opening section of this chapter's literature review seeks to expand our current knowledge and understanding the synthesis of landscape, building design and infrastructure. Current literature regarding ecological design asserts that designers must make a conscious decision to accept that these three design components should not be considered disparate elements that are the exclusive domain of discreet professional entities.

The literature asserted that future designers should seek to understand design from scientific, social, cultural and creative aspects. For ecological design to become a relevant design tool of the future, all of these perspectives must be acknowledged. There will probably never be a "unified vision" for ecological design, nor should there be. As Eckbo et al. (1998) note, the level of social and ecological consciousness that a designer may wish to bring to his or her work is a moral issue that cannot be made compulsory. However, if design professionals choose to take a leadership role with respect to ecological design and planning, then these professions will most likely take a leadership role in contemporary society.

Chapter Two demonstrated that rooftops have traditionally been indicative of local environmental conditions. That the typical rooftops constructed today remain divorced from their environment is a relatively phenomenon resulting from the emphasis placed on economic efficiencies.

This chapter explored the history and geography of rooftop verdure from Mesopotamian civilization, through to Classical Rome, Europe, Africa and North America The chapter then discussed innovations that made rooftop gardens a hallmark of Modern architects such as Le Corbusier and Frank Lloyd Wright. The chapter then marks the emergence of extensive green roofing in Europe and profiles the recent development of extensive roof greening in North America.

This chapter explored the ecology of the rooftop and discussed the need for cities to implement a "fully active biological epidermis" through the use of extensive green roofing as discussed by Prinz et al. (1981). This chapter explained how the environment of the rooftop differs from that at ground level and discussed how the unique qualities of the rooftop environment influence the design of extensive green roofing systems. Next this chapter gave a brief overview of the design components of flat roofing systems and explained the criteria that are used to differentiate intensive and extensive green roofs.

Section 2.7 of this chapter outlined the design, functional layers and construction of green roofing. The installation of components such as roofing membranes, root protection, insulation, drainage, substrate and vegetation were discussed. Particular attention was paid to the subject of fire precautions that should be considered and suggestions made by European experts.

Next, this chapter highlighted the problems that have been encountered with respect to the durability of green roofs. Issues surrounding the chemical incompatibility of roofing materials, the use of sub-standard materials and failure-prone single-layer systems were brought to light.

This chapter described four different categories of extensive green roof systems and discussed the benefits and cost of green roofing with respect the categories of amenity, economics, energy efficiency, the environment, and urban ecology. The role that extensive green roofs could play in the management of stormwater was then illustrated. Recommendations for further study that have been drawn from this literature are made in Chapter Six section 6.5.

Chapter Three – Participant Survey and Case Study Analysis

Chapter Three gathers, assembles and analyzes survey information from a questionnaire that was responded to by the seven owners and managers of green roofed buildings located within close proximity to the City of Winnipeg. One of the respondents owned two neighboring buildings that have installed green roofing (Sparks' Residence/North America Wetland Engineering). Due to the similarities of these roofs, both were analyzed under one case study. Therefore, although eight case studies are presented here, a total of nine buildings were profiled. Table 3.6 provides a summary of the survey results and can be found at the end of this chapter. Recommendations drawn from the results of this survey are made in section 6.6 of Chapter Six.

3.1 Geographic scope of the study

In addition to southern Manitoba, an area including Northwestern Ontario, southern Saskatchewan and northern Minnesota were determined to be an acceptable geographic range for the purpose of this study. These regions are exposed to continental weather conditions that are analogous to those found in the Manitoba Capital Region.

3.2 Survey objectives

The intent of this survey was to collect qualitative data from the owners and managers of existing green roofed buildings. In preliminary discussions, survey participants indicated that they had not collected quantitative data (i.e. data regarding thermal efficiency or stormwater retention) from their buildings. It was determined that collecting qualitative data from these participants would therefore be the focus of the survey.

Given the limited potential sample size, collecting data from as many participants as possible was essential. No limitations were placed on the size of the green roofs that were analyzed. The survey tool was designed to allow each participant to state their observations in their own words without limitation to a multiple-choice survey format. By using an open-ended questionnaire, participants were better able to express their attitudes, experiences and perceptions regarding extensive roof greening.

3.3 Survey methods

Upon developing an appropriate research protocol and survey tool, the information was submitted to the Joint-Faculty Research Ethics Board at the University of Manitoba. After minor revisions, the research protocol and survey tool were approved for use.

To locate relevant properties for the purposes of this analysis, manufactures, green roof industry representatives, engineers, planners, landscape architects and architects were contacted. Internet resources and List-serve groups were an extremely valuable source of contact information.

All participants received a package containing a cover letter, informed consent form, interviewee-briefing notes and a copy of the questionnaire. A minimum of three case studies were deemed as an acceptable sample size for purpose of this research, a total of nine building owners/managers were located and contacted, eight of which responded to the survey.

Participants had the option of a phone interview or complete the survey in written form and return it via mail, email or fax. The survey was first distributed to two participants, after which revisions were made in order to ensure the survey's effectiveness. Upon collecting and assembling the information into case study format, member checks were completed in order to corroborate the accuracy of each participant's responses.

Thirty-eight open-ended questions were posed to each participant. The questions were broken down into the following categories.

- General Information
- Roof Design
- Cold Climate and Green Roof Performance
- Rooftop Stormwater Retention and Local Watershed Health
- Surrounding Natural Environment
- Public Perception of Green Roofs
- Cost Savings and Losses
- Concluding Questions

Survey results are assembled and summarized within a case study format. Findings are noted in Section 3.5 of this chapter. The research protocol, briefing notes, survey and letter of approval can be reviewed in Appendix A.

3.4 Survey limitations

Because so few green roofs exist within the Manitoba Capitol Region, it was necessary to increase the geographic scope of the search. Nevertheless, the climatic conditions present in Minnesota are very similar to the conditions found in southern Manitoba. Minneapolis, Minnesota can experience temperature highs of 40.5°C and lows of -36°C. The mean annual precipitation of Minneapolis is approximately 38% greater than that of Winnipeg ("Minneapolis Climate Normals 1961-1990", 2001).

All participants opted to complete the survey form manually rather than be interviewed over the telephone. In leaving all of the questions open-ended (rather than asking participants to select a response according to a rating-scale), the case studies accurately indicate the individual opinions and attitudes of each participant. This allowed for an accurate qualitative analysis of the data collected.

3.5 Case studies

Within the geographic region investigated, one extensive green roof is in southern Manitoba and eight are in Minnesota. Buildings that have installed extensive green roofing could not be located within either Saskatchewan or Northwestern Ontario. Each of the nine case studies are described on the following pages.

Following the introductory information, the descriptions were presented in the following seven categories.

1. Roof design
2. Cold-climate performance
3. Watershed health and green roof stormwater retention
4. Relationship to the natural environment
5. Public perception
6. Cost savings/losses
7. Case summary

3.5.1 Anne Kletten Guest Cabin - Case Study One

Introductory information

Location	Walker Minnesota
Distance	430 km southeast of Winnipeg, Mb. Canada
Survey Participant	Anne Kletten
Building Type	Guest Cabin
Year of Green Roof Installation	1994
Size of Roof	524 square feet
Flat/Sloped Roof	Sloped

Roof design

This green roof was purpose-designed and constructed on a new building. Additional structural support was not required. The roof surface is 4x8 plywood, with a layer of roofing paper. A Planton roofing membrane was placed over the roofing paper. Chicken wire was then placed on top of the roofing membrane. On top of the chicken wire, a layer of sod was placed with the roots facing up. Next, a layer of 6-8 inches of soil was placed. Finally, a layer of Kentucky bluegrass was placed. The vegetation has not had any difficulty in becoming established on this roof. When the roof was first installed (and during periods of drought) this roof has been watered. In addition to the grass, wildflowers also grow on this roof. Regional snowfall or rainfall did not play a role in the design of this green roof. Cold weather and hot/dry weather were not a consideration in this design. Fire precautions were not a consideration in the design of this green roof. This roof has not suffered from membrane failure or any other defects or flaws and requires no mowing or maintenance.

Cold climate performance

The survey participant noted that the cold climate has not hindered or adversely affected the roof. In the opinion of this survey participant, green roofs are suitable for use in cold climates.

Watershed health and green roof stormwater retention

This participant did not note if this roof was located within a watershed. The participant affirmed that she had an understanding of the relationship between buildings, streets and other impervious surfaces and watershed health. Rooftop water retention did not play a role in the decision to install this green roof. There are few streets or buildings around the subject building. As a result runoff from impervious surfaces did not concern this participant. The participant does not measure runoff from this roof. However, the participant stated that that when it does rain, the roof retains water for a long time. This participant also noted that it must rain for an extended period of time before water begins to run off the roof.

Relationship to the natural environment

This participant noted that the decision to install the green roof was motivated primarily by aesthetics and that the roof was constructed according to Norwegian tradition. In the participant's opinion, the green roof has not made a significant improvement to the surrounding natural environment.

Public perception

The general public does not have good visual access to this green roof. Those who have viewed it have had a positive reaction toward the aesthetic appearance of this green roof. The survey participant feels that the roof educates people about the relationship of buildings, streets and other impermeable surfaces and it gives her the opportunity to explain this relationship to visitors.

Cost savings/losses

The participant noted that although the decision to install this green roof was not motivated by cost savings, savings have been realized through lower heating and cooling costs. There have been no unforeseen costs associated with this roof.

Summary

This participant expressed that the benefits of green roofing outweigh any initial concerns that she had with the system and that the problems associated with green roofing do not outweigh the initial enthusiasm. The participant rated the overall performance of her green roof as being "simply great".

3.5.2 Ducks Unlimited Oak Hammock Marsh Conservation Center – Case Study Two

Introductory information

Location	Oak Hammock Marsh, Manitoba, Canada
Distance	Located within the Manitoba Capital Region
Survey Participant	Bob Laidler
Building Type	Offices and interpretive center
Year of Green Roof Installation	1992 with major repairs in 1999
Size of Roof	50,000 square feet
Flat/Sloped Roof	Sloped

Roof design

The green roof that was constructed atop this facility was purpose-designed for the new facility. Additional structural support was required. A (liquid) torch on roof membrane was used on this facility. Topsoil with a custom blend of other materials was used as the growing medium. This roof has two different plant communities growing on it; one area contains native grasses, while the other area contains Kentucky bluegrass. The plants have had no difficulty in becoming established on the roof. To allow for drainage, this roof has a sloped design. Because of the cold weather, the roofing membrane has been placed underneath the roofing insulation (on the warm surface) rather than on the exposed surface. To compensate for hot and dry summer conditions, an irrigation system has been incorporated onto the roof surface. The irrigation system also ensures the health of the plants while protecting the roof against fire. The original EPDM roof membrane failed not long after installation. As a result the membrane was replaced in 1999 with the torch on system. The EPDM membrane likely failed because it was not the appropriate type of membrane for this size of roof and due to damage likely sustained during building construction. The participant noted that during construction there was a lot of foot traffic by trades people on the roof membrane, this may have contributed to the failure of this membrane.

Cold climate performance

The participant stated that the building's green roof was well suited to the cold climate of Manitoba. His experiences lead him to believe that green roofs are a suitable for use in cold climates.

Watershed health and green roof stormwater retention

The survey participant is well informed of the watershed in which his facility is located and understands the health of this watershed. The participant stated that he understands the relationship between buildings streets and other impervious surfaces with the health of the watershed. Despite this, rooftop water retention did not play a significant role in the decision to install the green roof. Rainwater is neither collected nor measured from this green roof. However the participant noted that the roof does retain some water. Because the soil used on this roof has a high clay content, the participant noted that most rainwater is shed from the roof.

Relationship to the natural environment

The participant remarked that this facility is located in an area considered to be environmentally sensitive. However, the decision to install a green roof was motivated by aesthetics rather than environmental concerns. In this participant's opinion, the green roof did not make a significant improvement to the surrounding natural environment.

Public perception

The general public has good visual access to this green roof. As a result, this has been beneficial to the public perception of the tenant. The participant mentioned that the public has had a positive reaction toward the aesthetics of the roof and that the roof serves to educate the public about the relationship of buildings and other impervious surfaces to watershed health. Planning authorities were very receptive to the installation of this green roof.

Cost savings/losses

The decision to install a green roof on this facility was not motivated by potential cost savings or losses. The participant stated that there might be some savings that can be attributed to lower heating and cooling costs. Although an amenable solution was reached between the architects and contractors who installed the original EPDM membrane, unforeseen costs that were encountered include the legal costs associated with filing the insurance claim to have this membrane replaced. Because EPDM is a floating membrane, water leaking underneath it often migrates to other locations on the roof. Seepage does not always occur directly below the leak, making the point of leakage difficult to detect. Because of the difficulty in detecting the source of the leak, the entire roof membrane had to be replaced at great cost. In addition to the costs associated with replacing the membrane, the cost of having the soil transported onto the roof and the cost of the materials blended into the topsoil were greater than originally anticipated. The current roof membrane is covered by a ten-year warranty.

Summary

Despite having its original EPDM membrane fail, the participant felt that the benefits of this green roof outweighed the costs. Overall, the participant is very pleased with the new system that is in place. The participant also noted that water is unable to pond on this roof due to the absorbent nature of the substrate. His experiences with conventional flat roofing led him to believe that ponds that occur on flat roofs contribute significantly to mosquito populations. He asserted that the green roof on the subject property remained relatively free of mosquitoes.

3.5.3 Long Lake Conservation Center – Case Study Three

Introductory information

Location	Palisade, Minnesota
Distance from Winnipeg	430 km southeast of Winnipeg, Mb. Canada
Survey Participant	Robert Schwaderer
Building Type	Education institution
Year of Green Roof Installation	1999
Size of Roof	100 square feet
Flat/Sloped Roof	Slightly sloped

Roof design

This green roof was constructed on a new building. No additional structural support was required. On top of a rubber membrane there is an 8-inch layer of soil that has been mixed with peat. The species used on this roof are native to the location. Being subject to below freezing temperatures for over seven months per year, hardy plant species were selected. Dry summers necessitated the planting of succulents on the roof. Fire precautions were not integral to this design. This green roof has not suffered any leaking or membrane failure. The plants required frequent irrigation in order to become established.

Cold climate performance

The participant noted that after a longer than normal winter, the plants on this rooftop are healthy and continue to grow vigorously. The participant noted that he felt that green roofs were "absolutely" suitable for use in cold climates.

Watershed health and green roof stormwater retention

This green roof is located in the Big Sandy Lake/Mississippi River watershed. The survey participant maintained that this is a relatively healthy watershed. As an environmental educator, the participant is very aware of the relationship between impervious surfaces and watershed health. Rooftop water retention was not a motivating factor behind the installation of this green roof. Although water from this roof is not collected or measured, the participant remarked that the plants on the roof are very healthy and therefore must be making use of the water that lands there.

Relationship to the natural environment

The participant considers this location to be environmentally sensitive. The decision to install this green roof was motivated partly by environmental concerns but also because the designer offered to donate the roof to the Conservation Center. The participant stated that the small size of this green roof limits the impact that it has on the surrounding natural environment. The participant advanced that if this green roof were larger and designed to work in concert with a natural wastewater treatment system (such as a constructed wetland), its impact on the surrounding environment would be much greater.

Public perception

The public has good visual access to this green roof. Visitors frequently notice the roof and inquire about its "odd appearance". The public reaction to this green roof has been generally positive. Because the green roof is used as in interpretive educational tool, it has been very useful in educating the public with respect to the relationship between impervious surfaces and watershed health. Planning authorities were very receptive toward the installation of this green roof.

Cost savings/losses

There have been no cost savings or losses associated with this roof.

Summary

The participant affirms that after observing the roof perform over the past three years, the benefits of this roof outweigh the costs. Problems associated with green roofs have not outweighed the participant's enthusiasm toward this roof. The participant rates the overall performance of this green roof as being "excellent".

3.5.4 Phillips Eco-Enterprise Center –Case Study Four

Introductory information

Location	Minneapolis, Minnesota, USA
Distance	675 km southeast of Winnipeg, Mb. Canada
Survey Participant	Michael Kraus
Building Type	Commercial/industrial (office/light manufacturing)
Year of Green Roof Installation	May 2000 to June 2001
Size of Roof	4,000 square feet
Flat/Sloped Roof	Flat

Roof design

This green roof was purpose-designed and built on a new building. Additional structural support was required. A layer of heated bitumen was put down to provide waterproofing On top of this a recycled plastic waffleboard was placed. A layer of pea gravel was then placed over the waffleboard. The waffleboad and pea gravel act as a drainage layer. A cloth filter layer has been placed on top of the pea gravel. Nine inches of soil have been placed on top of the filter fabric. Although the membrane, filter system and soil of this roof were put down in May 2000, the vegetation will be planted in July of 2001. The participant remarked that the plants that have been identified for use are indigenous riparian species that can be found in the area. These plants were chosen for their adaptability to shallow soil environments and their tolerance of temperature and moisture extremes. The vegetation was also chosen as part of a low-impact xeriscape strategy. Once established, these plants will require no mowing, watering or fertilizing. Regional precipitation, temperature and wind were taken into consideration during the design of this roof. Although cold weather was not a major concern in this design, the effects of frost heave were taken into consideration. Fire precautions were not a consideration in this design. A drip irrigation system has been installed on this roof. The participant affirmed that this system would be used during the first two seasons only. Although the materials for this roof were locally available, European experts were consulted.

Cold climate performance

Although this roof is still under construction, the cold climate has not posed any difficulties to the roof. The participant noted that, in his opinion, green roofs are suited for use in cold climates.

Watershed health and green roof stormwater retention

This green roof is located in the Minnehaha Creek watershed. The participant expressed that he is generally familiar with the health of this watershed. When asked if he understood the relationship between buildings, streets and impervious surfaces and the health of the watershed, the participant noted that "impervious surfaces are a major cause of non-point water contamination". The participant acknowledged that runoff from the roof is not measured. However, runoff from the roof drains into a 3-tiered wetland area on the side of the building. After a 2-inch rainfall, the roof did not appear to retain much rainwater as the overflow tanks were full. The lack of water retention on this roof might be attributed to the fact that the roof has yet to be planted. The respondent noted that he expects the roof to retain a significant amount of rainfall once the plants are established.

Relationship to the natural environment

The participant maintained that this green roof was not located within an area considered environmentally sensitive. The decision to install this green roof was motivated primarily by environmental concerns. The participant asserted that he expects this roof to make a significant improvement to the surrounding natural environment.

Public perception

15 million vehicles per year are able to view this green roof from an elevated bridge nearby. In 2003, a new light rail system will also give riders a view of the roof. The participant remarked that the green roof educates the general public about the relationship between impervious surfaces and the health of watersheds. Although they had to be educated in advance, planning authorities were receptive to this green roof.

Cost savings/losses

Long-run cost saving were not considered in the decision to install this green roof. Cost savings, if any, have not been calculated. The cost of transporting the soil onto the roof was a greater expense than originally estimated.

Summary

The participant feels that the benefits of green roofing outweigh the initial concerns and that the problems commonly associated with green roofing have not outweighed the participant's enthusiasm for green roofing. Though still new, the participant rated the performance of this green roof as being "excellent".

3.5.5 Ravenwood Studios and Residence – Case Study Five

Introductory information

Location	Ely, Minnesota, USA
Distance	350 km southeast of Winnipeg, Mb. Canada
Survey Participant	Jim Brandenburg
Building Type	Commercial/residential
Year of Green Roof Installation	1994
Size of Roof	1,500 square feet
Flat/Sloped Roof	Flat and sloped

Roof design

The green roof placed on this commercial/residential building was built for use on the new structure. Additional structural support was added to this building in order to accommodate the green roof. The components of this design include two layers of rubber membrane and a 6-inch topsoil layer. Plants used on this roof include grass seed from various sources, native plants, herbs and small trees. These plants experienced a small amount of trouble in becoming established. This participant asserted that regional snowfall, rainfall, cold weather and hot/dry conditions did not play a role in the design of this roof. Fire precautions were a small consideration in the design of this green roof. The roof on this facility has not suffered from membrane failure or any other defects.

Cold climate performance

The survey participant noted that the cold climate of its location had not adversely affected the green roof. The participant affirmed that his experiences lead him to believe that green roofs are suitable for use in cold climates.

Watershed health and green roof stormwater retention

This green roof is located in the Moose Lake watershed. In the participant's opinion, this watershed is very healthy. The participant stated that he had a slight understanding of the relationship between buildings streets and other impervious surfaces with the health of the watershed. Rooftop water retention did not play a significant factor in the participant's decision to install a green roof. Although the participant does not measure runoff from this roof, he expressed that the roof does retain a significant amount of runoff.

Relationship to the natural environment

Although the participant mentioned that the subject building is located in an area that is considered to be environmentally sensitive, the decision to install this green roof was not motivated by environmental concerns. The participant remarked that any improvements made to the surrounding environment by the roof are unknown to him.

Public perception

The general public does not have good visual access to this green roof. However, the survey participant stated that the green roof has helped – rather than hindered – the public's perception of the tenant. The public has had a positive reaction to this green roof. The participant stated that the public has reacted in this way because the building relates to its natural environment and creates a better fit with its natural surroundings. The participant stated that the subject property educates the public about the relationship between buildings and the natural environment. Planning authorities were very receptive toward the installation of this green roof.

Cost savings/losses

The decision to install this green roof was based on aesthetics rather than potential cost savings. The participant noted that any savings attributable to lower heating and cooling costs are unknown. There have been no unforeseen costs associated with this green roof.

Summary

The participant affirmed that although problems associated with green roofs could perhaps outweigh initial enthusiasm, the benefits associated with the installation of this green roof outweighed any initial concerns that he had. This participant noted that he feels generally pleased with the performance of this green roof.

3.5.6 Rice Creek Gardens Inc. – Case Study Six

Introductory information

Location	Blaine, Minnesota, USA
Distance	675 km southeast of Winnipeg, Mb. Canada
Survey Participant	Harvey Buchite
Building Type	Storage facility (commercial)
Year of Green Roof Installation	1999
Size of Roof	280 square feet
Flat/Sloped Roof	Sloped

Roof design

This green roof was retrofitted onto an existing facility. Supplemental structural support was required. This roof has a fairly steep pitch to it. A roofing membrane was installed with grid liner on top of the membrane that holds the soil in place. There is a 3-inch layer of substrate and two drainage outlets. One hundred and sixty-five different varieties of plants have been used on this roof. The plants are made up of native prairie plants as well as alpine plants. These plants have had no problem in becoming established on the roof. Regional climate and precipitation were not a consideration in the design of this roof. Fire precautions were not a consideration in the design of this roof. Because of its pitch, this roof has been subject to some soil loss and water drainage problems. The participant notes that the prefabricated grid that holds the soil in place could be designed better. Because these grids are too wide, some soil loss has occurred. In addition, the participant acknowledged that the drainage outlets on this roof are not functioning properly and need to be redesigned.

Cold climate performance

The participant remarked that the cold local climate has not had an adverse affect on this roof. In the participant's opinion, green roofs are suitable for use in cold climates. The cold climate has altered the plant species that are able to survive on this roof.

Watershed health and green roof stormwater retention

This participant is familiar with the watershed that the facility is located within. However, the health of this watershed is unknown to the participant. Both rooftop water retention and the aesthetic look of green roofs played a role in the participant's decision to install this green roof. The participant does not collect or measure runoff from this green roof. This green roof does retain some rainwater but the participant did not think that it detained a significant amount. This is likely a result of the steep slope of this roof.

Relationship to the natural environment

This green roof is located in a plant nursery that contains display gardens. The decision to install this green roof was motivated by environmental concerns. The participant noted that this roof has had a positive impact on the surrounding gardens but did not note if the roof has benefited the wider natural environment.

Public perception

The general public has good visual access to this roof. The participant states that the roof has been beneficial to the public's perception of the owner. The public has had a positive reaction toward this roof. The participant observed that others have expressed an interest in installing a green roof on their own property upon seeing this roof. Although this roof creates a general awareness of green roofing, the participant does not feel that this green roof serves to educate the public about the relationship between impervious surfaces and watershed health. Planning authorities were noted as being "ambivalent" to "warmly receptive" regarding the installation of this green roof.

Cost savings

The decision to install this green roof was not motivated by potential cost savings. However, the participant explained that the building is much cooler in the summer with the green roof (this building is not heated in the winter). Unforeseen costs include some of the maintenance that has been performed to the roof.

Summary

This participant feels that the benefits of green roofing outweigh initial concerns and that problems encountered have not outweighed his initial enthusiasm for these systems. The participant rated the performance of this roof as being "quite good" and stated that with some redesigning; the roof would function even better. The steep pitch of this roof is noted as being a challenge to the design.

3.5.7 Sparks Residence/ North American Wetland Engineering (NAWE) – Case Studies Seven & Eight

Introductory information

Location	Forest Lake, Minnesota, USA
Distance	675 km southeast of Winnipeg, Mb. Canada
Survey Participant	Curtis Sparks
Building Type	Two separate properties, residential garage roof and detached commercial shed that houses equipment for North American Wetland Engineering
Year of Green Roof Installation	Personal residence (1998), commercial shed (1999)
Size of Roof	Residence (2,583 square feet), shed (1,615 square feet)
Flat/Sloped Roof	Residence (flat), commercial shed (sloped)

Roof design

The green roof was retrofitted onto the residential garage while the green roof on the detached equipment shed was purpose-designed. Neither building required additional structural support in order to accommodate its respective green roof. Both roofs are layered with a 40ML EPDM membrane, 9Lb geotextile, a second layer of 40ML EPDM and a 2-inch mixture of black earth and peat. To facilitate drainage, all edges of the buildings have a border of 3/8-inch pea gravel. On both buildings, twenty different plant types were used. These include a variety of succulents, sedges, onion and flax.

The selection of soil, drainage medium and plants were based on regional climate. The cold winter climate as well as the dry summer conditions heavily influenced the selection of plants used on these two roofs. The hot dry weather greatly influenced the soil selection. The vegetation did not have any problems becoming established. Fire precautions were not a consideration in the design of this green roof. The detached commercial shed is the only structure to have experienced soil loss. The survey participant stated that some soil loss occurred during a heavy rain not long after the roof was installed on the detached shed. This may have been a result of the shed roof being sloped. The survey participant noted that a layer of netting placed over the roof might have prevented this from happening.

Cold climate performance

The cold climate caused some winterkill on these roofs. However, over time the hardy plant varieties replaced the plants that died off. Overall, the survey participant indicated that green roofs are well suited to cold environments. A central purpose for the installation of these roofs of this roof was to demonstrate their suitability to cold climates.

Watershed health and green roof stormwater retention

The survey participant indicated that these buildings are located within the Forest Lake Watershed, Minnesota. The participant indicated that he is very familiar with the overall health of this watershed. This individual confirmed that he understood the relationship between buildings, streets and other impervious surfaces with watershed health. Although he affirmed that stormwater retention is an important benefit of green roofing, he explained that it did not play a significant role in the decision to install a green roof.

The survey participant has not collected/measured runoff from either of these buildings. However, he noted that the green roof on the residential building appeared to detain a significant amount of water while the sloped roof on the detached roof detained a less significant amount of rainwater. The participant noted that both roofs reduce runoff noticeably.

Relationship to the natural environment

Being located within an environmentally sensitive area, the decision to install these two green roofs was based on broad environmental concerns. The survey participant suggested that these two green roofs had not made a significant improvement on the surrounding natural environment. Rather, the roofs were meant to demonstrate their suitability to cold climates and demonstrate the importance of incorporating ecology with design.

Public perception

Members of the general public do not have frequent visual access to these green roofs. Though not a high-traffic area, people working in the commercial building have reasonable visual access to the green roof. The aesthetics of these green roofs is considered beneficial to both properties. The survey participant stated the decision to install these roofs was partially motivated by aesthetics and that the roofs are a very attractive feature. The survey participant noted that the public has had a positive reaction toward the aesthetic appeal of these roofs and that the roofs have served to educate the public about the relationship of buildings and other impervious surfaces to watershed health. When questioned about the receptiveness of planning authorities toward these roofs, the survey participant mentioned that the planning authorities were not told of these roofs.

Cost savings

The decision to install these green roofs was not motivated by cost savings. Because neither building is heated or cooled, cost savings associated with heating/cooling cannot be calculated. The staff of North American Wetland Engineering frequently comments on how cool the equipment shed is on hot summer days. Unforeseen costs include the bi-annual weeding of these roofs.

Summary

The survey participant stated that he had no concerns regarding the effectiveness of these two green roofs prior to their installation. The survey participant has had no problems with these roofs and remains enthusiastic about their effectiveness in the cold climate. The survey participant rates the overall performance of these roofs as being excellent and appreciates the attention that they receive. Because the survey participant is the president of an environmental based civil engineering firm, he acknowledged that these roofs provide the public with an example of a better way of living.

3.5.8 Residential Garage Roof – Case Study Nine

Introductory information

Location	Minneapolis, Minnesota, USA
Distance	675 km southeast of Winnipeg, Mb. Canada
Survey Participant	Jim Nestingen
Building Type	Unheated residential garage
Year of Green Roof Installation	1998
Size of Roof	576 square feet
Flat/Sloped Roof	Flat (slight slope for drainage)

Roof design

This roof was constructed over an existing garage. New structural supports were added. Copper flashing was used along the roof edge. The roof surface is ¾" plywood, on top of the plywood is felt board covered with a 60ml EPDM waterproofing membrane. A landscape fabric was placed on top of the EPDM membrane. Sod was then rolled out over the roof surface. Because a crane could not get high enough over a power line to drop soil on the roof, five layers of sod were placed one on top of the other. This "sod-layering" technique is reminiscent traditional Norwegian green roofing techniques. Regional snowfall and rainfall were a consideration in the design of this roof. Because the roof is in a shady location, hot/dry weather was not a concern in the design. Fire precautions were not taken into consideration in the design of this roof. This roof has not suffered from any form of membrane failure. There is no drainage layer incorporated into the design of this roof. The drainage layer was omitted to save time, cost and weight.

Cold climate performance

The grass on this roof experienced some winterkill after the first season. The ceiling of the garage was later insulated to temper the conditions at the root zone. Overall, this survey participant feels that green roofs are well suited to cool northern climates.

Watershed health and green roof stormwater retention

This green roof is located in the Minehaha Creek watershed. The participant is aware of the health of this watershed. The participant is also aware of the relationship between impervious surfaces and watershed health. Rooftop water retention was not a significant factor in the decision to install this green roof. The participant does not measure the amount of runoff from this roof. Because this roof lacks a drainage layer the participant noted that it retains a significant amount of water.

Relationship to the natural environment

This facility is located in an urban setting and is not located in or adjacent to an environmentally sensitive area. The decision to install this green roof was motivated by environmental concerns (loss of green space by garage expansion).

Public perception

The public has good visual access to this green roof. The participant notes that the public has had a positive reaction to this roof. Local media coverage has made the owners "local celebrities". The participant feels that the green roof educates the public about the relationship of buildings streets and impervious surfaces to watershed health. Planning authorities attempted to deny the building permit for this roof. The authorities could neither approve nor disapprove of the roof because regulations for green roofing do not exist in the jurisdiction in which the roof is located.

Cost savings

The decision to install this green roof was motivated by cost savings. The garage on which the roof is located was to be expanded. The cost of putting on a gabled roof that would have matched the character of the participant's home would have been greater than that of putting on a green roof. In addition, this green roof has added to the functional green space that would have otherwise been lost to the garage expansion. Unforeseen costs associated with this green roof include the insulation of the garage ceiling so as to mitigate damage within the root zone.

Summary

The participant feels that the benefits of this green roof outweigh any initial concerns that he had, and that the problems associated with this green roof have not outweighed his initial enthusiasm. Overall, the participant is very pleased with this green roof.

3.6 Survey Findings

Findings have been drawn from the analysis of the survey data and the nine case studies that were subsequently assembled. The information is arranged according to the following format.

- Age and location of subject properties
- Green roof design
- Cold climate performance of green roofing
- Watershed health and green roof stormwater retention
- Relationship of green roofs to the natural environment
- Public perception and understanding of green roofs
- Cost savings/losses

A summary table of these findings can be found in Table 3.6 at the end of this section.

3.6.1 Age and location of subject properties

Installed in 1992, the Ducks Unlimited Oak Hammock Marsh Conservation Centre green roof is the oldest of all roofs studied. The roof on the Phillips Eco-enterprise Centre, completed in 2001, is the most recent. It is easy to see that extensive green roofing is new to this region of North America. Because of this, observations that relate to the long-term durability of extensive green roofing within the study area are difficult to make. The Ducks Unlimited property has undergone extensive repairs due to membrane failure resulting from damage that likely occurred during the installation of its green roof.

Of the nine buildings profiled, all but two are located in a rural setting. The Phillips Eco-enterprise Centre and the Nesitngen garage are the only green roofs that are located within an urban environment. All others buildings are located in relatively small towns and in secluded settings. This suggests that there may exist some hesitation with respect to using green roofs within highly visible urban locations and that a lack of appropriate building codes and zoning regulations may also be hindering the use of extensive green roofing.

3.6.2 Green roof design

The green roofs studied range in size from 100 square feet to 50,000 square feet. Five out of the nine buildings profiled required supplemental structural support. Regardless of the size of their respective green roofs, all respondents were aware of the types of systems that were in place on their roofs. Four of the eight survey respondents were directly involved in the design and construction of their green roofs. These respondents appear to have a better knowledge of the built components of their respective green roofs.

Soil depths and membrane types vary for all of the green roofs studied. Some soils contain manufactured admixtures while others use peat. Many of the roofs use unaltered topsoil. Soil depths range from 2 to 9 inches. The two subject properties that had suffered from soil erosion were both sloped roofs. The survey participants familiar with these roofs recommended that, under circumstances where soil loss has occurred due to the slope of the roof, design modifications should be made. In one subject property, soil was lost during the period in which the plants had yet to take hold. In this circumstance it was suggested that netting be placed on top of the soil to bind it in place as the plants take hold. The owner of the Ricecreek Garden's roof (which has a large pitch) noted that soil loss has been problematic even after the plants became established. In this case, the survey participant suggests that a smaller grid size in the manufactured sheeting that holds the soil in place would mitigate this problem. The loss of soil associated with pitched roofs led to the blockage of roof drainage in one of these roofs. This could lead to excessive roof moisture and roof loadings in excess of acceptable limits.

All roofs contained a mix of both native and non-native plants, or used native plants exclusively. In all examples where non-native vegetation dominated, rooftop irrigation was required. Though well thought out, plant selection involved a process of trial and error as the more hardy plants replaced those unable to survive. In this respect, subject roofs went through a period of transition until a stable plant community was established. Only two of the seven respondents affirmed that native vegetation had difficulty in becoming established.

Only one of eight survey respondents acknowledged that fire precaution was a "small consideration" in the design of their roof (Case Study Five). All others stated that fire was not a consideration in the design. However, all but one roof utilized native vegetation. As referenced in the Chapter Two, Drefahl claims that because many species of native vegetation remain green during times of drought, using native plants on green roofs can be a form of fire protection (1997). Irrigation systems, which were installed on the two largest of the eight buildings investigated, act as an additional form of fire protection.

Of the nine roofs profiled within this study, eight roofs use variations of commonly accepted extensive green roofing methods. The Kletten property and the

Nestingen property are the only structures within the study that utilized traditional rather than modern green roofing techniques.

3.6.3 Cold climate performance of green roofing

The single adverse affect of cold climate on the subject properties was the winterkill of plants. Participants acknowledging that winterkill was a problem observed that the more hardy plants were quick to replace plants that did not survive. The effect of frost heave was considered in the design of only one of these roofs. Of nine roofs reported on, only three respondents affirmed that the cold climate was considered in the design their roof. All participants were unanimous in their assertion that green roofs were suitable for use in cold climates.

Despite the wide range of soil types and depths, all participants maintained that their roofs are suited for use in cold climates. On roofs with a mere 2 inches of soil (Case Studies Seven and Eight)), the plants have survived the cold northern winters. One participant had to insulate the ceiling of his green roofed garage so as to temper the conditions of the root zone and thereby mitigate against excessive winterkill (Case Study Nine).

3.6.4 Watershed health and green roof stormwater retention

All survey participants confirmed they were familiar with the watershed that their building was located within. In addition, all participants asserted they understood the relationship between impervious surfacing, runoff and watershed health. Only one of the nine buildings profiled (Case Study Six) noted that stormwater retention was integral to the decision to install the roof.

None of the survey participants has measured the amount of runoff from their green roofs. Three participants noted their roofs retained some water and five participants noted that their roofs retained a significant amount of water. One participant noted that his roof retained some water but because it consisted of soil only and had yet to be planted it was retaining less than its full potential (Case Study Four). Participants who owned sloped roofed buildings stated that stormwater retention occurred but was negligible.

One participant declared that the use of green roofs in retaining stormwater was possible but could be greatly enhanced if green roofs were designed to work in concert with constructed wetlands (Case Study Four). The Phillips Eco-enterprise Center in Minneapolis, Minnesota, has integrated a three-tiered wetland onto the side of the facility. Any roof runoff that flows off of the roof enters the wetland system.

3.6.5 Relationship of green roofs to the natural environment

Although seven of the nine subject properties are located in rural areas, five of the nine were confirmed as being located in or adjacent to ecologically sensitive areas. When asked if the reason for installing a green roof was based on broad environmental concerns, four participants affirmed this response. The location of the building within an environmentally sensitive area was correlated to the environmental motivation to install the green roof on three instances. Three participants noted that environmental concerns were not the prime factor in their decision to install a green roof. These three participants acknowledged that the aesthetics of green roofing was the most significant motivating factor. Supplementary responses included the importance of blending ecology with design and the desire to employ traditional building techniques.

3.6.6 Public perception and understanding of green roofs

All respondents observed that their green roofs were well received by the general public. In addition, the survey participants were unanimous in acknowledging that their roofs serve to educate members of the public about green roofing and the relationship between impervious surfaces and stormwater runoff. Two of the buildings were educational/interpretive centers, one of which used their green roof building as part of their curriculum.

Given their predominantly rural settings, most of the buildings did not experience high volumes of public traffic. Rice Creek Gardens, a commercial greenhouse experiences some public visitors. The reaction to this roof by the public has been very positive. The owner noted that one individual had decided to install his own green roof after seeing the Rice Creek green roof.

The green roof having the greatest public exposure is the Phillips Eco-enterprise Center. Occupants of 15 million vehicles per-year are able to see this roof from an adjacent motorway. Because this roof has yet to be planted, the public has not yet had the opportunity to observe it in its finished form.

3.6.7 Cost savings and losses

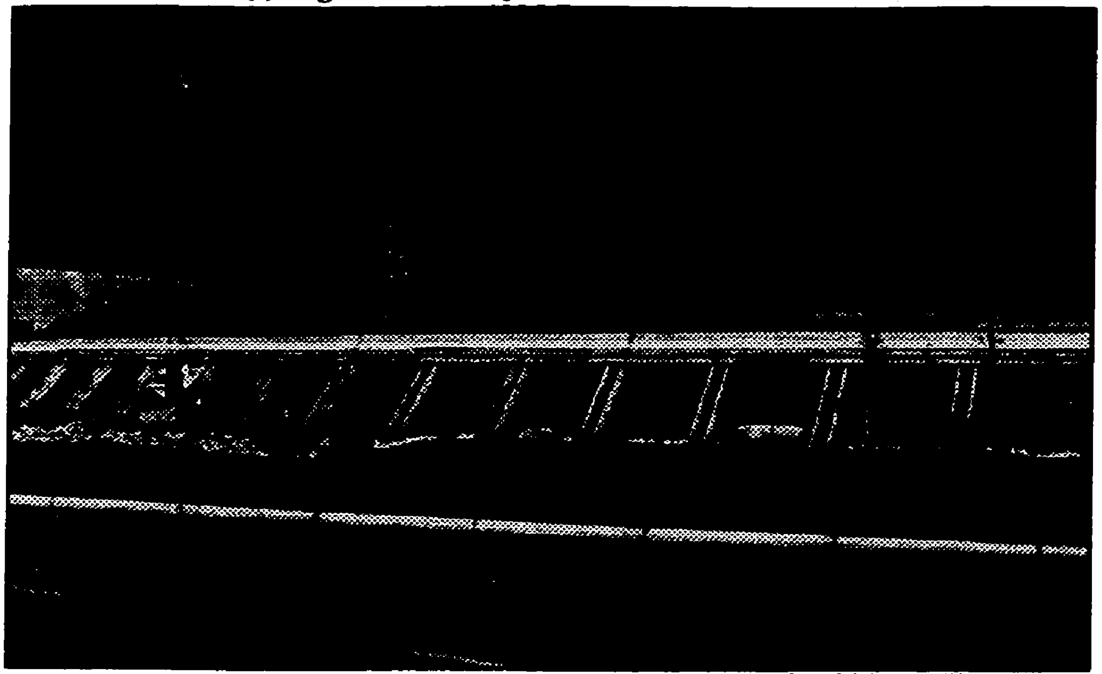
Seven out of eight participants remarked that their decisions to install green roofing were not motivated by potential cost savings. None of the participants who had retrofitted green roofing onto an existing building took measurements in order to determine if the thermal efficiency of their buildings had increased. Of the nine buildings studied, one building was considered to have superior thermal efficiency and one building was observed as being very cool in the summer.

The survey participants managing the two largest facilities surveyed expressed that the cost of transporting the growing medium onto the roof was greater than originally expected (Case Studies Two and Four). Two participants recognized that yearly weeding and inspection must be conducted on their roofs. Although the time required to do so is minimal, this maintenance requirement was largely unexpected. One participant brought noted the unexpected legal costs of settling an insurance claim related to the replacement of a failed roofing membrane and the replacement cost of a new membrane (Case Study Two). One participant noted the unexpected costs associated with having to insulate his roof in order to moderate the soil temperature at the root zone (Case Study Nine).

3.7 Chapter summary

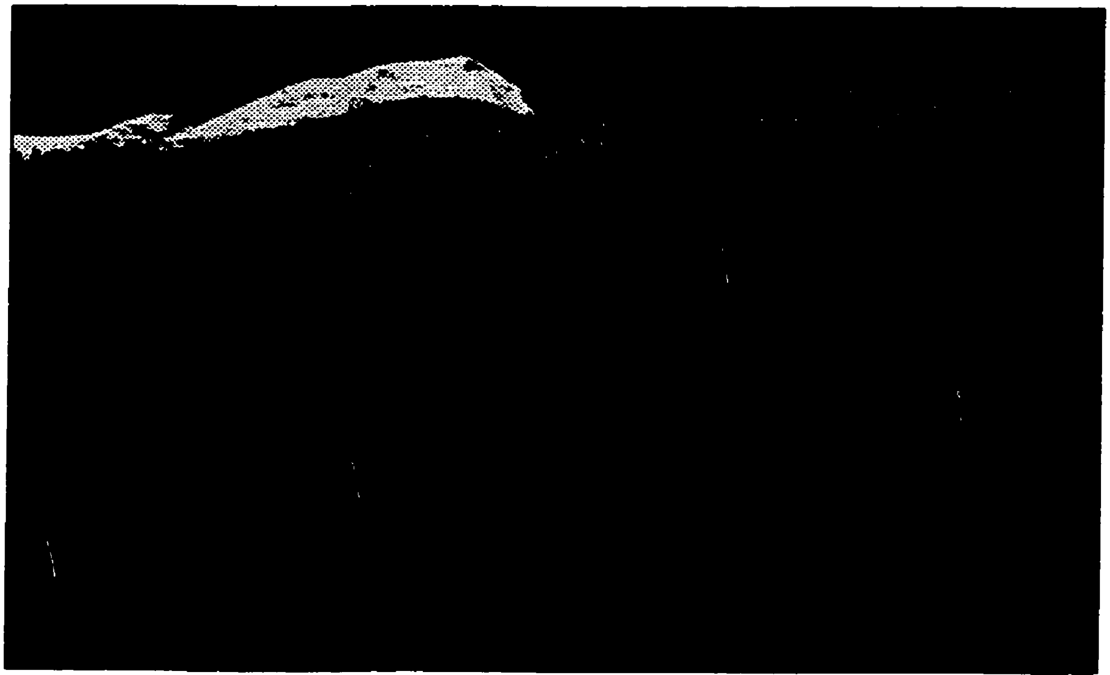
Although three of the nine buildings profiled were noted to be suffering from some form of defect, the participants remained enthusiastic about their roofs. Five of the buildings were given an overall rating of "excellent", one roof was rated as "fine",

Illustration 3.7(a) Rogers Pass Interpretive Center in summer



(David Van Vliet)

Illustration 3.7(b) Rogers Pass Interpretive Center in winter



(David Van Vliet)

and two were rated as "good". All participants believe that the costs associated with green roofing do not outweigh the initial concerns regarding these systems and that any problems encountered have not outweighed their initial enthusiasm for green roofing. This suggests that these roofs are certainly more than mere "fads" that are soon to disappear. The owners and managers of these facilities remain pleased with the functional performance, environmental fit and visual appearance of their green roofs.

One study participant noted that water ponding common to standard flat roofs could not occur on his green roof. Largely inaccessible, these temperate ponds otherwise become excellent incubators for mosquito larvae. This participant noted that green roofs could provide a natural means of potentially curbing mosquito problems in urban centers. The City of Winnipeg entomologist noted that although flat roofs do contribute to mosquito populations, the conditions must be right. If the rooftop pond temperatures are too hot and there is no organic material on the roof, mosquito populations will be unable to survive. With the adequate organic content, water and the right temperature, mosquitoes can thrive (personal communication with Randy Gadawski, July 16, 2001). The potential effects of extensive green roofs on mosquito populations have not been studied.

All survey participants were unanimous in affirming that extensive green roofing is suitable to cool northern climates. Soprema Roofing, the only company currently able to install extensive green roofing in the City of Winnipeg under their Sopranature© brand of roofing is convinced of the viability of the systems in cold climates (personal communication with G. Harrison, June 22, 2001). In a written statement, a European green roof industry representative of Zin/Co GmbH, an innovative company at the leading-edge of green roof design, it was expressed that extreme cold temperatures have not had any effects on their green roofing systems (personal correspondence with J. Gessner, March 9, 1999).

To further illustrate cold-climate performance record of these systems, a green roof was constructed on a portion of the 52,000 sq. ft. Legislative Assembly Building of the Northwest Territories. P. Briggs, a landscape architect and restoration ecologist with the firm EDAW, communicated that plant materials were taken from the site, propagated at the University of British Columbia greenhouses, and returned to the site for use on the roof. Plant mortality was high at first. This was likely a response to being returned to a sub-artic environment from the UBC greenhouses. Nevertheless, the roof has been a success (personal communication with P. Briggs, April 19, 2001).

Table 3.6 Summary of Participant Responses to Green Roof Survey

KEY: Y=Yes, N=No, ♦=No response/Not applicable

Information / Owner	*Case Number*	*R=Rural, U=Urban*	*Roof area (square feet)*	*Year installed*	*R=retrofit on existing building, B=New building*	*Supplemental structural support required*	*S=Sloped, F=Flat C=Combination*	*Membrane: Floating rubber = F Torch on (liquid) = T*	*Soil Depth (inches)*	*I=Indigenous Plants used F=Non-native plants used, M=Mix*	*Plants have had difficulty in becoming established*	*Roof designed to withstand cold*	*Green roof was adversely affected by cold climate*	*Participant affirmed that green roofs are suited for use in cold climates*	*Local precipitation considered in design*	*Fire precautions designed into roof*	*Facility located in/adjacent to an environmentally sensitive area*	*Green roof was installed for environmental reasons*	*Roof has a positive impact on natural environment*	*Green roof installed mainly for aesthetic reasons*	*Survey participant understands the relationship between impervious surfaces and watershed health*	*Green roof was installed for stormwater retention*	*Runoff is retained by the roof (1=some water retention, 2=significant water retention)*	*Public is receptive to the appearance of the roof*	*Roof serves an educational purpose*	*Planning authorities were receptive to the roof*	*Overall rating of the subject roof by participant*
Kletten Cabin	1	R	524	1994	B	N	S	Fl	7	M	N	N	N	Y	N	N	N	N	N	Y	Y	N	2	Y	Y	♦	Excellent
Ducks Unlimited	2	R	50,000	1992	B	Y	C	T	♦	M	N	N	N	Y	N	♦	Y	N	N	Y	Y	N	1	Y	Y	Y	Good
Long Lake Conservation Center	3	R	100	1999	B	N	S	F	8	I	Y	Y	N	Y	Y	N	Y	Y	N	N	Y	N	1	Y	Y	Y	Excellent
Phillips Eco-Enterprise Center	4	U	4,000	2000/ 2001	B	Y	F	T	9	I	♦	N	N	Y	Y	N	N	Y	Y	N	Y	N	2	Y	Y	Y	Excellent
Ravenwood Studios	5	R	1500	1994	B	Y	C	F	6	I	Y	N	N	Y	N	Y	Y	N	♦	Y	Y	N	2	Y	Y	Y	Fine
Rice Creek	6	R	280	1999	R	Y	S	F	3	M	N	N	Y	Y	N	N	♦	Y	Y	Y	Y	Y	1	Y	Y	N	Good
Sparks Residence	7	R	2,585	1998	R	N	F	F	2	I	N	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	2	Y	Y	♦	Excellent
NAWE	8	R	1,615	1999	B	N	S	F	2	I	N	Y	Y	Y	Y	N	Y	Y	Y	N	Y	N	1	Y	Y	♦	Excellent
Nestingen Garage	9	U	576	1998	R	Y	F	F	♦	F	N	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	2	Y	Y	N	Excellent

Chapter Four - Site Selection and Analysis

The analysis of the 43-acre study site located adjacent to Omand's Creek in the City of Winnipeg will begin with an exploration of the underlying principles that have influenced the natural drainage régime of the Manitoba Capital Region. Pristine or altered, all landscapes are heavily influenced by factors such as topography, soil, vegetation and climate. In this context, the natural history of the Manitoba Capital Region will be briefly discussed. The relationship between riparian habitat and watershed health will also be noted.

The land drainage regime that exists in the Manitoba Capital Region today is not only a product of the natural history of this province, but it is also a product of its social history. As Omand's Creek makes up a part of the study site used within this research, it is necessary to chart the historical changes that have altered this creek. The need to drain land northwest of Winnipeg City for the purpose of agriculture has led to significant changes in the configuration of Omand's Creek. The diversion projects that have played a fundamental role in shaping present-day Omand's Creek and its associated watershed will be discussed in their chronological order.

The final section of this chapter defines and analyzes the location of the Omand's Creek study used within this study. This analysis describes the condition of the habitat surrounding the site, the health of the riparian corridor adjacent to the site, and investigates the impact that recent development has had on the site. Building footprints, surface treatments, drainage patterns and the location of sub-grade infrastructure are noted within this chapter.

4.1 Natural history of the Manitoba Capital Region

To gain an understanding of the impact that urbanization has had on the native landscape of Manitoba, a discussion of the natural history of the province is essential. In both urban and unaltered environments, the amount of water that drains overland into streams and channels is determined by the amount of rainfall that falls in excess of what the land is capable of absorbing. In any unaltered landscape, this excess is determined by topography, climate, soil, vegetation, and rainfall intensity (Graham, 1984). Although the same principles hold true for urban landscapes, the extent to which the above factors have been altered by development is crucial to the rate of runoff (Graham).

In whole or in part, the native landscape inevitably forms the foundation of all development. By gaining an understanding of the native landscape, one can better grasp the wider implications of urban development. The maturity of streambeds, the rate at which soil is able to conduct water, and the type of vegetation present are the unique results of the natural history of place. These variables play an integral role in the hydrology of all landscapes.

4.1.1 Topography

Teller (1984) notes that over the past several million years, Manitoba has been subject to the effects of glaciation. The Wisconsonian ice advance, the most recent glacial advance to have altered the Manitoba landscape, began to retreat about 16,000 years ago. When these glaciers began their final retreat, they created the Lake Agassiz basin. The boundaries of this basin were formed by the retreating ice front to the north, the high land of Minnesota to the south, the high land of Northwestern Ontario to the east, and the Manitoba escarpment to the west (Teller).

The level topography of the Winnipeg area is the result of the deposition of glaciolacustrine materials brought into Lake Agassiz by a system of rivers and streams. As the lake began to recede into the central lowlands, sand and silt poured into its calm waters. "Lake currents distributed the material with the finer particles, the silts and clays being carried to the center of the lake which is today the approximate center of the Red River Valley and the location of the City of Winnipeg" (Graham, 1984, p.27). It was during these successive glacial movements that water-laid till was deposited directly on top of the preexisting bedrock and dense basal till foundation (Teller, 1984). Following this, a layer of glaciolacustrine silty clays (gumbo) and silts were deposited over much of the southern Lake Agassiz basin. Up to 15 meters in depth, these silts now mask hills and valleys that once formed the lake bottom (Teller).

Within Winnipeg and the Red River Valley, micro-relief is evident in the form of low clay ridges that give the area a very slightly undulating appearance. Even in areas where the topography appears to be flat, slight depressions of no more than a few centimeters below the general level are common (Graham, 1984). When combined with the relatively impervious nature of the silts and clays, this micro-relief accounts for alternating areas of intermittent marsh that are common to the prairie landscape (Graham). Despite extensive urban development, evidence of the micro-relief that has resulted from our glacial heritage can still be found within the City of Winnipeg.

4.1.2 Soil

The soils that are common to the Winnipeg region were developed via the fine clay deposits of the central plain of glacial Lake Agassiz. As a result of the level topography and high water retention values associated with lacustrine clays, these soils have been subject to excessive levels of moisture. Once saturated, the soils of the Red River Valley become relatively impervious (Graham, 1984). Local micro-relief has resulted in a variety of drainage regimes. As a result, soil types with distinct characteristics have resulted. Red River clay, Osborn clay, and Fort Garry clays underlie the City of Winnipeg. The most important feature of these soils is their fine texture and their low hydraulic conductivity (Graham, 1984).

The soil infiltration capacity, the rate at which water is absorbed by the soil, is an important factor in land drainage. Soil infiltration capacity is determined by soil texture, soil structure, vegetative cover, biologic structures, antecedent soil moisture, and conditions of the soil surface (Graham, 1984, p.29). Rainfall that exceeds the rate of infiltration flows off the land into drainage networks or is stored in the numerous topographic lows found within the City of Winnipeg and its surrounding municipalities (Graham).

4.1.3 Vegetation

Most of southwestern Manitoba falls within the transitional grassland ecoclimatic region. This region is composed of mixed-grass and tall-grass prairie. It is within this region that moisture deficits place a considerable stress on woody species. These conditions are favorable to herbaceous grassland species (Scott, 1996). The sub-humid climate of this region has historically promoted the late-summer dieback of herbaceous cover. These dry conditions have led to a regular regime of human and lightning induced fires. This burning has greatly influenced the soil development and the dominant biota of this region (Scott).

Prior to its agricultural transformation, Winnipeg and the lowlands of the Red River Valley were dominated by tall-grass prairie. The loam-based soils of this area, coupled with an average of 50.4 cm of precipitation per year, provided excellent growing conditions for tall-grass prairie. Once the most productive types of prairie in North America, less than 1% of Manitoba's original tall grass prairie remains ("Habitat Profiles", 1999). The topographically low central basin of the glacial Lake Agassiz, "Supported lush grasslands, wetlands, and long, narrow riverine forest, and it represented an extension of the tall-grass prairie stretching north from the Dakotas" (Smith, 1996, p.47). Native prairie ecosystems are dominated by a mixture of native perennial grasses, wildflowers, and low-growing shrubs ("Habitat Profiles", 1999) which have developed special adaptations in order to overcome extremes in temperature and precipitation. While simultaneously helping the plants reduce moisture loss, downy or rolled up leaves serve to protect the plants from both frost and from sunlight. Deep root systems act as nutrient storage sinks that provide access to water held deep beneath the surface.

The dominant woodland communities found within this region include aspen parkland and river-bottom forest. The aspen parkland ecosystem is a forest type that seeks a dynamic equilibrium between forested bluffs of trembling aspen and prairie grasses such as Canada wild rye, and big bluestem. A natural regime of prairie fire kept these two plant communities in balance with one another. Aspen stands, which are eliminated through fire, are quickly blanketed with prairie grasses. In the absence of burning, aspen stands creep back onto the prairie through underground rhizomes. Sunlight is readily able to penetrate through the canopy of the aspen forest which allows for the growth of a wide variety of shrubs and grasses in the understory of the aspen forest ("Habitat Profiles", 1999).

River bottom forest grows along the edges of creeks, rivers and streams. The silts deposited by early spring flooding replenish the soil with nutrients and enable the growth of a variety of tree species. In return, the roots of these trees stabilize the stream and riverbanks while helping to reduce erosion ("Habitat Profiles", 1999). Trees such as willow and cottonwood dominate the lower portions of river bottom forest. These species are able to withstand seasonal flooding and damage from ice breakup. Higher up the riverbank, trees such as basswood, green ash, American elm, and Manitoba maple dominate ("Habitat Profiles", 1999). Many flowers, grasses and low shrubs also exist here. Plants that prefer drier habitat, such as the bur oak, dominate the highest section of the riverbottom forest.

The character and amount of local vegetation greatly influence the rate of stormwater runoff. The infiltration of moisture into the soil is promoted by leaf surfaces that intercept and slow the rate of rainfall (Graham). The humus resulting from decaying leaf and grass litter absorbs moisture, while plant cover returns moisture to the air through evapotranspiration. Graham (1984) notes that the character of local vegetation affects the height of the water table and thus the infiltration capacity of the soil.

> The more massive the vegetation, the more water it absorbs and transpires into the atmosphere; and this water is drawn either from the ground water supply or from the soil before it penetrates to that level.
>
> (Garham, 1984, p.30)

Studies have indicated that a mere 10% of all precipitation that falls on native prairie vegetation results in runoff (Graham, 1984).

4.1.4 Climate

Unless otherwise stated, the data used in this section is derived from the period 1961 to 1990, the most recent thirty-year period during which normals have been calculated. To fully understand the climate of Manitoba, the geographic and topographic features that influence the elements of temperature, precipitation and wind must be considered. These features include latitude, relief and geographic location.

With its southern-most boundary at 49°N, the Manitoba Capital Region is considered part of the mid-latitudes (35°N-55°N). Latitude affects the amount of solar radiation that the surface of the earth is exposed to. It is an integral factor in determining the amount of solar energy available at the surface of the earth to heat the ground, the air, evaporate water or melt snow (Blair, 1996). The latitude of Manitoba is high enough to produce significant seasonal variations in day length (Blair). As a result, southern Manitoba experiences 8 hours of sunlight during its shortest day of the year and 16 hours of sunlight during its longest day. This extreme variation in the amount of incoming solar radiation is the primary factor behind this seasonal variation in temperature (Blair).

Resulting from southern Manitoba's limited topography, air masses from all directions are able to flow into the province without impediment. Accordingly, Blair (1996) notes, "Manitoba can be affected from bitterly cold air masses from the Arctic, mild air originating from the North Pacific, dry air-streams from the American Great Plains, and even tropical flows from the Gulf of Mexico" (p.33). The movement of these air masses leads to frequent collisions and severe frontal activity.

One of the most significant controls of the climate of southern Manitoba is its location. Positioned near the center of the North American land mass and on the leeward side of the Rocky Mountains, the province is largely unaffected by the moderating influences of large open bodies of water (Blair, 1996). The distance of the province of Manitoba from the Pacific Ocean is of extreme significance to its thermal regime. The Pacific Ocean greatly alters the temperature of the air masses that pass over it. Because the surface temperature of the Pacific Ocean remains thermally inert throughout the year, this body of water has a cooling effect on the land during the summer and a warming effect in the winter. Manitoba's distance from the Pacific Ocean prevents its moderating effects from impacting the local climate. Southern Manitoba has little thermal inertia. As a result of this, the land and shallow lakes heat up very quickly during the spring and summer months, and cool off just as rapidly as winter approaches (Blair, 1996).

Oceans are more than just heat sinks. They are also important sources of precipitation and moisture. Moist air masses that pass over the Rocky Mountains deposit most of their moisture on the windward side of the mountains. Blair (1996) notes that "This, in conjunction with warming caused by subsidence of the air towards the lower elevations of the Prairies, produces the so called rainshadow effect, characterized by a much drier regime on the downwind side of a topographic barrier than on the upwind side" (p.33). Despite the result of the rainshadow effect, most of the moisture that falls in Manitoba originates from the Pacific Northwest. However, considerable amounts of precipitation occasionally reach Manitoba in the form of moist air masses that progress northward from the Gulf of Mexico.

The temperature of Manitoba undergoes frequent day-to-day, season-to-season, and year-to-year variability. With a daily maximum mean temperature of 19.8°C, the warmest month of the year in Winnipeg is July ("Canadian Climate", 1998). January is the coldest month of the year with a daily mean temperature of –18.3°C ("Canadian Climate", 1998). Temperature ranges in southern Manitoba are characterized by wide fluctuations in diurnal, daily, seasonal, and annual temperatures (Blair, 1996). On average, there are about 250 days per year in southern Manitoba where the temperature rises above 0°C, while the average frost-free period is 115 to 125 days long ("Canadian Climate", 1998).

Spring and fall within southern Manitoba are transitional seasons. Each of these seasons is short in duration and both are characterized by rapid changes in average daily temperature. In comparing the changes in the mean temperature during winter and summer months to those of the spring and fall, Table 4.1 illustrates the severity of these changes that occur during transitional periods.

Blair (1996) attributes these rapid changes in temperature during the spring and the fall to changes in day length and sun intensity (a function of latitude) and albedo (heat absorption). A mass with low a albedo is able to absorb and store more energy than one with a high albedo. Blair notes that in late spring, as winter snow pack is in its final stages of melting, there is a sudden lowering of surface albedo. This promotes the absorption of solar electromagnetic radiation, which in turn leads to higher air temperatures and increased snowmelt. Conversely, following the first snowfall, surface albedo is suddenly raised. The decrease in heat absorption leads to a decrease in ambient air temperature and produces the low temperatures that are necessary to prevent snow melt.

Table 4.1 Changes in Mean Temperature During Transitional and Non-Transitional Months

Time Period	Number of Days	Classification	Change in Mean Temperature
April 1 to May 31	61	Transitional	18 °C increase
June 1 to July 31	61	Non-transitional	5° C increase
October 1 to November 30	61	Transitional	20°C decrease
December 1 to January 31	62	Non-transitional	9°C decrease

(adapted from Blair, The Geography of Manitoba, 1996, p.35)

The average annual precipitation in Winnipeg is approximately 535 millimeters per year, of this, about 20 to 25% falls as snow ("Canadian Climate", 1998). June, July and August experience 57% of the seasonal rainfall and 46% of the yearly precipitation ("Canadian Climate", 1998). The majority of this precipitation falls during frequent summer thunderstorms. Winnipeg experiences approximately 20 severe thundershowers from the beginning of June to the end of August ("Canadian Climate", 1998).

In addition to frequent periods of drought and extended periods of rain, extreme rain and snowfall events are not uncommon to the region. Extreme daily rainfall and snowfall in Winnipeg have been recorded at 83.8mm and 35.6cm respectively ("Canadian Climate", 1998). The precipitation that falls as snow in southern Manitoba sublimates or evaporates during dry cold days (Graham, 1984). In the spring, the remaining snow melts while the ground remains frozen. Moisture is thus retained on the surface. In the spring, if soil is moisture laden because of late seasonal rains, spring runoff may be exacerbated (Graham, 1984).

Using information derived from the Hudson's Bay Archives, settlers' diaries and journals, dendrochronological analysis, studies of lake level variations, and instrumental data, studies have determined the frequency of average and non-average precipitation years. It has been determined Southern Manitoba experiences average precipitation levels 26% of the time, below average precipitation 40% of the time and wet seasons 34% of the time (Graham, 1984, p.37)

As an overall trend, the pressure patterns that occur in southern Manitoba are influenced by warm unstable air from the eastern seaboard or the Gulf of Mexico and cool polar air from the north. In the summer, if the position of the polar air mass remains over southern Manitoba, above average moisture may be expected. Below average precipitation will likely result if the polar air mass remains farther north (Graham, 1984). The average wind speed in Winnipeg is 18 km/h. In general, northerly and northwesterly winds tend to occur more than others. Extreme gust speeds have reached up to 129 km/h.

Despite the seasonal and annual variability in climate, the weather in Winnipeg does have some endearing qualities. Most notably, Winnipeg experiences approximately 2377 hours of sunshine every year, 38% of which occurs between June and August.

4.2 The implication of natural history on runoff and urban development

The level topography of the province, coupled with the nature of the soils deposited by glacial Lake Agassiz, has resulted in a natural drainage system that is extremely sensitive to human disturbance. Few depressions exist for excess runoff to drain into, and fine-textured soils prohibit the rapid movement of moisture downward toward the water table. Development that does not account for such factors will exacerbate these naturally existing conditions.

With humus and native vegetation absorbing and filtering moisture, and the upper forest canopy capturing and slowly releasing rainfall to the earth's surface, native plant communities have adapted to become extremely valuable buffers and cleansers of precipitation. When development eliminates large amounts of vegetation, the existing drainage courses become overburdened and polluted. Soils erode, river and stream banks fail, and water flows too quickly to allow for adequate aquifer recharge.

The level topography, latitude, continental location, and distance from the moderating influence of oceans have created a climate that poses additional difficulties to site drainage. Most notably, precipitation and temperature are subject to swift and extreme fluctuations. Spring runoff is rapid and frequent while summer thundershowers result in intense rain events.

Despite the fact that the Manitoba Capital Region has a drainage regime that is highly sensitive to land development, zoning by-laws do little to mimic the preservation of the natural drainage regime. Instead, water is drained off of the land as quickly and efficiently as possible. In not paying adequate attention to natural landscape conditions, the balance of drainage, absorption, filtration, evaporation and recharge are subsequently neglected.

4.3 The hydrologic impacts of urbanization in the City of Winnipeg

As noted throughout this document, by their extensive use of impermeable surface treatments, urban growth has greatly altered the surfaces of our cities. These surfaces are designed to repel water rather than allow it to into the water table. As a result our streams and rivers are being inundated with water flowing from this abundance of impermeable surfacing. Table 4.3 below summarizes the effects of increasing levels of impermeable surfacing materials on river and stream health.

The City of Winnipeg requires that all new developments restrict site runoff to the pre-development rates of flow (personal communication with G. Kincade, February 16, 2001). Flow control is achieved through the construction of sub-grade water retention reservoirs, retention ponds, parking surfaces that hold water during extreme rain events, and rooftop rainwater retention. In the event of an intense rain event, new developments must be capable of retaining a volume of water equal to the entire non-permeable surface area of the site at a depth of one foot (personal communication with G. Kincade, February 16, 2001). This requirement ensures that storm sewers, sewage treatment plants and our rivers and streams are not inundated with runoff during times of heavy rainfall.

As well intentioned as this requirement is, it is not a by-law. Under this condition, its effectiveness is debatable. Eventually, all of the water that is stored on site is released into our storm drainage infrastructure and the natural hydrological regime remains neglected. This regulation does not account the increases in runoff that are attributed to developments that pre-date this regulation.

Table 4.3 - The Effect of Impermeable Surfacing on Rivers and Streams

Impermeable surfacing within watershed (%)	Indicators of stream health/degradation
0	Presence of woody debris, even flow, good substrate, good riparian cover, healthy fish and insect communities
7	Stream degradation becomes detectable, 20% increase in runoff into the stream system
8-10	Visible effects become noticeable, widening of channels, sediments from the floodplain are washed into the stream system and create new silt/sand/rock bars within the stream bed. To maintain a sensitive high-quality stream system, the 10% impervious mark should not be exceeded
10-25	At 25% most of the visual components of a healthy stream remain, however many other important aspects of stream ecosystem health will be degraded
25-45	The stream becomes a non-supporting system which will not allow for biological or human uses. At 45% impervious cover, streams more than double in width and depth, there is severe undercutting of the normal stream bank and riparian area, multiple poorly-functioning channels may form

(adapted from Schuler, Integrating Stormwater into the Urban Fabric, 1996, p.22-33)

Like most other cities that experienced rapid growth in the late nineteenth century, Winnipeg relies on a system of combined sewers. During the spring thaw and during periods of heavy rain, the capacity of combined sewers is surpassed. When this occurs, a mixture of rainwater and sewage are surcharged into the Red and Assiniboine Rivers. This occurrence is known as a combined sewer overflow (CSO).

CSOs into the Red and Assiniboine Rivers occur approximately 30 times per year ("Combined Sewers", 2001).

In the mid-1930s, it became obvious that the Red and Assiniboine Rivers were becoming too polluted by raw sewage flowing directly into their waters. Shortly thereafter, the City began constructing sewage treatment plants. In the 1950s, the construction of combined sewers was halted. Since this time, all new sub-divisions have been built with separate sewer systems where rainwater and sewage are collected in separate pipes. At present, combined sewers service 40% of Winnipeg with 75 outflows being located along the Red and Assiniboine Rivers ("Combined Sewers", 2001).

The City of Winnipeg has been monitoring the effects of CSOs on the aquatic life of the Red and Assiniboine Rivers. Following a CSO, oxygen is needed to break down the newly deposited organic matter. The breakdown of organic matter in water results in the production of ammonia. The City of Winnipeg Department of Water and Waste notes that the effects of CSOs on biochemical oxygen demand (BOD) and ammonia are minimal. Other pollutants deposited into our rivers and streams following a CSO include suspended solids, hydrocarbons, and heavy metals. These diffuse pollutants accumulate in the water body that they are deposited into and result in environmental degradation (Cigana, 2000). Following a CSO, bacteria from human and animal waste is also washed into our waterways. These bacteria can cause skin and eye irritations as well as flu-like illnesses. The provincial government has established water quality standards for municipal wastewater effluent. On recommendation from the Canadian Council of the Ministers of the Environment, these standards, summarized below, were adopted by the Provincial Department of Conservation. Effluent quality must achieve the following standards:

1. 200 fecal coliform organisims/100ml (may be applied on a seasonal basis)
2. 30 mr/L Biochemical oxygen Demand
3. 30mg/L Total Suspended Sediments (excluding growing algae)
4. (Manitoba Conservation, 2001)

According to Cigana, the best management practices with regard to hydraulic discharge currently available include:

1. Achieving source control of stormwater flow rates.
2. Creating retention capacity upstream in the sewer system.
3. Optimizing overflow weir capacity.
4. Increasing end-of-pipe capacity of the wastewater treatment facility.

(Cigana, 2000, p.51)

Cigana notes that the focus should be on slowing the transfer of stormwater into the stormwater infrastructure. Cigana states that, "Peak flow reduction has been shown to prevent the hydraulic surcharge of the sewer, eliminate some overflow events and increase conveyance at the wastewater treatment facility"(p.51). Many inexpensive technologies can be used to control the flow rates of stormwater runoff. Front-end solutions include inlet control devices (ICDs) such as vortex flow regulators; orifice plates, stormwater infiltration devices, ponding systems and swales can be used to regulate runoff. Though not identified by the author, green roofs would fall under the category of inlet control devices.

Researchers have investigated different ICDs used in CSO reduction. Source control was compared to traditional CSO control systems such as in-line storage, off-line storage and deep tunnel storage. Source control was found to be the most cost effective and flexible solution when compared to all alternatives (Cigana, 2000). The estimated cost of source control for the city of Evanston, Illinois was less than 50% of the cost of all other alternatives (Cigana). Another study reported a peak flow reduction of 92% with the implementation source control methods of stormwater reduction (2000). Used in conjunction with other ICDs, green roofs could become an effective means of controlling stormwater at the source. Green roof technology could help to attain the provincial standards for effluent quality by limiting the problems associated with combined sewer overflows.

At current rates of renewal, the City of Winnipeg's sewage and stormwater infrastructure is being replaced once every 700 years! In 1996, the amount of money being spent on the City's sewer system was approximately one-fifth of the necessary maintenance cost (CH2M, 1996, p.7). At an estimated cost of four billion dollars, tearing up and replacing combined sewers with a system of separate sewers is prohibitively expensive. Other suggestions to have been put forth include creating upstream effluent storage facilities. The current cost estimate for widespread surface drainage controls for the City of Winnipeg range from four hundred million to one billion dollars ("Combined Sewers", 2001).

With revenues of between three and five million dollars per year, the operation of the City of Winnipeg's sewage system is self-financed. Funds are secured through tax revenue and through surcharges placed on industrial/commercial users. Winnipeg's most recent sewage treatment plant was constructed at a cost of two hundred million dollars. In 1996 one hundred and fifty-seven million dollars remained outstanding on this debt (CH2M, 1996). Owing to the disparity between revenues and capital costs, it would be of great benefit to the City of Winnipeg to explore infrastructure renewal options that do not rely on large injections of capital. To date within the City of Winnipeg, there have been no studies completed that have looked at source control as a means of alternative stormwater management. The stormwater infrastructure of each Canadian city is unique. An analysis that explores each of the four best management practices (as noted by Cigana) should be conducted by the City of Winnipeg.

The potential for using green roofs in the City of Winnipeg as a source control for non-structural means of stormwater management must not be overlooked. The problems associated with stormwater effluent pollution, sewer back-ups, and flooding could be better controlled by the use of extensive green roofing. Green roof infrastructure is an important and frequently overlooked part of a comprehensive stormwater management strategy (GRIM, 2000).

Other cities are undertaking studies and programs geared toward developing a green roof strategy. For example, the City of Portland is in the process of developing a program that will provide financial incentives to encourage the use of green roofs. These incentives will be based on giving new and existing buildings reduced lot level fees for stormwater management. The City of Portland considers green roofs to be a legitimate stormwater management technique ("Overview", 2001). The City of Toronto is developing a "Wet Weather Flow Management Master Plan" which explores all options available in the prevention, control and reduction of pollution in stormwater runoff (GRIM, 2000). Winnipeg should aim to follow these models of incentive and research.

Unlike predominant techniques of water retention, extensive green roofing has a wider range of environmental benefits (see table 2.6, p.49). Collateral benefits from the implementation of extensive roof greening include; the capacity to filter pollutants out of rain water, fewer combined sewer overflows, the reduction of water in overburdened rivers and streams, the reduction of greenhouse gasses, and the lessening of the effects of the urban heat island.

The benefits associated with improved stormwater quality and quantity have been an important motivating factor in preceding cases where municipalities have accepted the use of extensive green roofing (Peck, 1999). The city of Winnipeg is not immune to the ecological consequences that are a result of urban development. Winnipeg frequently experiences extreme runoff events during the spring thaw and during intense summer storms. This trend suggests that, rather than being exposed to a steady flow of low-intensity runoff, stormwater infrastructure is periodically inundated by intense rain events. The result of infrequent but intense rain events, in conjunction with our use of antiquated infrastructure, suggests that Winnipeg stands to benefit immensely from further exploring the benefits of an extensive roof greening strategy.

4.4 An historical analysis of the Omand's Creek Watershed

The general pattern of the land in Winnipeg and its surrounding regions runs in a northwest to southeast direction. The streams and tributaries that drain into the Red and Assiniboine Rivers follow this age-old course. Omand's Creek is one of a group of creeks located in the northwest quadrant of the City of Winnipeg. Of the original eleven creeks within this quadrant, Omand's Creek, Colony Creek, Sturgeon Creek, Truro Creek and Selkirk Creek are all that remain (Graham, 1984).

Flowing from the northwest, water enters Omand's Creek from the higher lands of the Manitoba Escarpment and Lake Manitoba (Graham, 1984). Although some creeks in this quadrant have matured to developed deep creek beds capable of conveying large volumes of water, most are relatively young and therefore limited in their ability to convey heavy flows of water. Prior to European settlement, "Considerable ponding occurred as these waters flowed across the prairies, and marshes formed in wet years" (Graham, 1984, p.37).

In understanding the boundaries of the Omand's Creek Watershed it is necessary to peel back the layers of history that have led to its present-day form. The earliest Europeans to come to the province of Manitoba settled along the fertile soils of the well-drained levees of the Red and Assiniboine Rivers. Easy access to these waterways outweighed any of the risks associated with spring flooding. Over time, as the lands directly adjacent to these rivers became occupied, the settlers began to move onto marginal land. The move to these marginally drained lands necessitated the first agricultural drains (Graham, 1984). Since this time, prairie potholes and marshlands have been viewed as impediments to the development of agriculture. In 1859, H. Y. Hind, a surveyor, publicly declared the economic benefits of land drainage.

> If the drainage of many thousand square miles of swamp and marsh in this part of the country should ever become a question of national interest, I know of no enterprise of the kind which could be executed with so little cost and labor, and promise at the same time such widespread beneficial results.
> (Graham, 1984, p. 49)

As the City of Winnipeg experienced its earliest spurts of urban growth, C. P. Brown, the Minister of Public Works for Manitoba had great power over decisions regarding land drainage within the City of Winnipeg and the Province of Manitoba. Brown noted that the flooding caused by several consecutive years of wet weather could be mitigated only through the development of an efficient drainage system (Graham, 1984). The reasoning behind this notion was based on the political desire to attract and maintain immigrants who, "Were either deterred from entering the province, or were forced to pass through it and settle on drier plains." (Graham, 1984, p. 50)

Early maps of Omand's Creek show the creek as being a small tributary that originated approximately 6 km north of Portage Avenue and slightly west of the present-day perimeter highway. The creek then flowed southeast and terminated inside of Brookside Cemetery. In wet years, water from the East and West Branches of Colony Creek would flow through less mature streams and into Omand's Creek.

The winding bottom reach of present-day Omand's Creek, was originally known as Catfish Creek. Prior to 1880, Catfish Creek terminated at the present-day location of Empress Street and Maroons Road. Today, the remnants of this twisting and turning portion of the creek are easily identified.

The most significant alteration made to Omand's Creek is known as the Colony Creek Diversion. Completed in the early 1880s, this linear 5 km diversion linked Catfish Creek with the upstream portion of Omand's Creek in Brookside Cemetery (Graham, 1984). To further strengthen this diversion, the rail lines of the west branch of the CPR were constructed east of Omand's Creek. In the event of flooding from the creek, the rail lines would prevent water from flowing into central Winnipeg (Graham). After several name changes, "upper" Omand's Creek, Catfish Creek and the Colony Creek Diversion became know as "Omand's Creek". These earthworks thereby facilitated drainage of the West and East Branches of Colony Creek into the Assiniboine River via Omand's Creek.

Prior to the Colony Creek Diversion, the waters of Colony Creek fanned outward in a southeast direction through a system of coulees, ponds and undeveloped streams. These streams terminated at a series of outfalls located in the heart of downtown Winnipeg. These outfalls included the Colony Creek outlet located at present-day Colony Street, as well as the Brown's, Logan's, Prichard's, St. Johns and Inkster's outlets (Graham, 1984, p.37)

As Winnipeg grew, the natural system of coulees, ponds and immature streambeds that conveyed and stored water were filled in and the land was built upon. As a result of the loss this natural water conveyance system, downtown Winnipeg experienced frequent floods. The Colony Creek Diversion was seen as the natural solution to this problem.

Despite the diversion which enable the draining of the East and West branches of Colony Creek into Omand's Creek, "Severe flooding was experienced in the City of Winnipeg due to the waters of Colony Creek in 1880 and again in 1882" (Graham, 1984, p.79). Nevertheless, embankments were repaired and grades re-established. Within twenty years there would be few traces remaining of the original drainage coulees and outfalls that had once been a highly visible component of downtown Winnipeg.

By late 1880, the waters draining into Omand's Creek included the West and East Branches of Colony Creek, as well as numerous agricultural drains. As a result of this diversion, the drainage area Omand's Creek was approximately 189 km^2 (Manitoba Natural Resources, 1987). With such a large area draining into a comparatively small creek, frequent flooding, erosion and stream bank failure resulted.

In 1966 the West Branch of Colony Creek was diverted away from Omand's Creek and into Sturgeon Creek. This diversion reduced the drainage area of Omand's Creek by 114 km^2 (Manitoba Natural Resources, 1987). In 1974 and again in 1979, significant flooding was experienced along Omand's Creek. In order to protect downstream development from floodwaters originating in the northwest, a small dam has since been constructed in the upper end of Omand's Creek within Brookside Cemetery.

4.5 The present-day watershed of Omand's Creek

Omand's Creek is as much a product of human history as it is natural history. It has evolved to become a major drainage basin serving a large area northwest of Winnipeg. With the West Branch of Colony Creek being diverted away from Omand's Creek in 1966, the present-day watershed now drains 75 km^2 of land (Manitoba Natural Resources, 1987). As defined in 1987 by Manitoba Natural Resources, the drainage pattern of the creek is as follows.

> Omand's Creek originates in Township 12, Range 1 E.P.M., approximately 6.5 kilometers northwest of the Perimeter Highway of the City of Winnipeg...The upper reach of Omand's Creek is named East Branch of Colony Creek....[flowing from the northwest Omand's Creek] cuts across

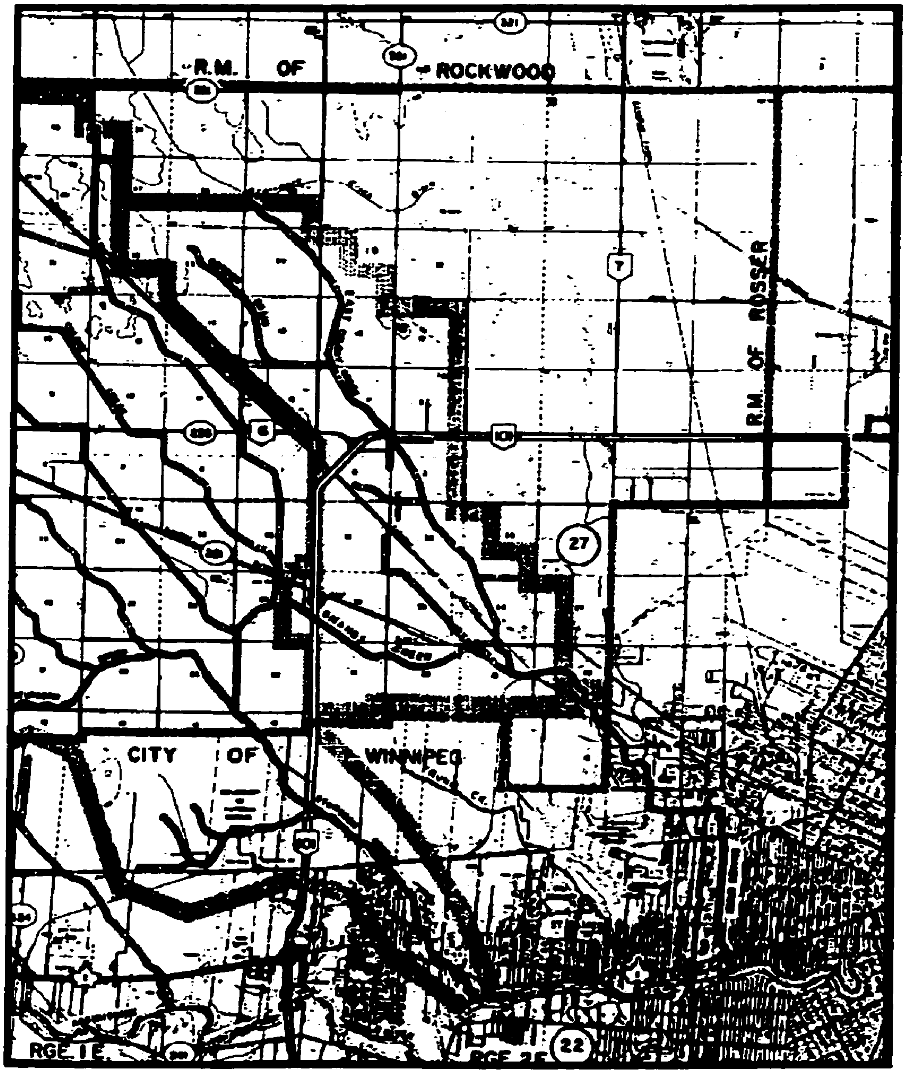
> Brookside Cemetery, flows south near Red River Community College, turns west at Keith road and along Dublin Avenue, then takes a Southerly course along Empress Street and empties into the Assiniboine River through a ravine west of Raglan Road.
>
> (Manitoba Natural Resources, 1987, p.2)

Despite an elaborate network of land drainage channels that has been developed throughout the rural municipalities of Manitoba, a succession of wet years have placed additional strain on this system. The Association of Manitoba Municipalities is looking to increase the amount of agricultural land that will be drained into the Omand's Creek watershed. When coupled with increased urban development around the creek, this proposed increase in drainage area is likely to increase the flood risk associated with Omand's Creek (personal communication with A. Nagy, April 30, 2001). Illustration 4.5 (following page) contains a map image of the area covered by the watershed.

4.6 An analysis of the urban downstream reach of Omand's Creek

Runoff from urban sources is drained directly into Omand's Creek. Over the past 50 years, urban development has encroached upon the edge of the creek bank. In the past, developers have been granted approval to go so far as to place concrete piles directly into the creek bed and build parking structures that overhang the creek (as done at Wellington Avenue). Owing to the lax practice of earlier planning authorities regarding the ecological protection of the creek, public criticism over the poor treatment of Omand's Creek by neighboring commercial/industrial property owners is frequent.

Illustration 4.5 The present-day watershed of Omand's Creek



(Manitoba Natural Resources Water Resources Branch. 1979)

It is within the downstream reach of Omand's Creek that the evidence of poor watershed health is most apparent. Significant changes to the hydrology of the urban portion of this watershed form the foundation of this problem. Fischenich, Sotir & Stanko describe the causes of urban creek bank degradation as follows,

> Urbanization increases the impervious area, decreases the time of concentration of overland flow, and reduces long-term upland sediment yield. For a given rainfall event, urbanization yield's more runoff and delivers this

runoff to the channel more quickly than for other existing land uses. The runoff includes less sediment but more heavy metals, fecal coliforms, and other pollutants. The increased runoff and decreased sediment yield erode the bed and banks of stream channels within the watershed until the channels reach a new equilibrium given the post-development hydrology and sediment delivery characteristics. Resulting channels are often several times the size of their pre-development condition. This erosion often takes decades to complete and the impacts on infrastructure are immense. Flooding and property loss from erosion are only part of the picture. It is virtually impossible to place a dollar value on environmental impacts, such as lost flora and fauna, but many direct costs can be identified. For example, nearly every bridge, culvert, pipeline crossing, and other structure located within the erosion corridor will eventually require replacement or repair – a significant capital cost for the community.

(Fischenich, Sotir & Stanko, 2001, p.2)

Goldsborough and Gurney (2001) completed a water quality study on Omand's Creek and found that,

> Water quality ratings at sites along Omand's Creek ranged from "marginal" to "fair". Water quality was poorest in the stream reach with the heaviest concentration of commercial and industrial development. There was no significant difference in water quality over the four-year period (1995-1998) for which data were available. This study indicates that conditions in Omand's Creek have deteriorated as a result of passage through the City of Winnipeg but, in general, no more so than in other urban streams.
>
> (Goldsborough & Gurney, 2001, p.1)

Private landowners are not exclusively responsible for the polluted state of this creek. West of Wellington Avenue, the remains of a decommissioned landfill that has been redeveloped into Westview Park borders the creek. Leachate from this former landfill is a confirmed source of non-point creek pollution ("Paddling", 2001). Salts from a nearby City of Winnipeg snow dump also pollute the site ("Paddling", 2001).

Graham (1984) notes that the linear portion of the creek that runs from Notre Dame Avenue and connects with the original Catfish Creek bed adjacent to Maroons road has been heavily encroached upon by industrial development. A portion of the

1880 Colony Creek Diversion, this linear stretch is capable of carrying 456 cubic feet of water per second. Unfortunately, in extreme runoff conditions it is subject to 950 cubic feet of water per second (p. 130). Stadnyk (1999) notes that Omand's Creek is now, "For the most part, a wide drainage ditch where waters, struggling to regain their meandering pattern, and over-burdened by the addition of unnatural surface drainage, inflict erosion and slumpage along the banks" (p. 24).

Recent bank stabilization projects along Omand's Creek have occurred within the urban downstream reach of the creek. Many of these projects have occurred on sites that are privately owned. Pursuant to City of Winnipeg Waterway By-law 5888/92, waterway permits are required when construction may endanger the stability of river or creek banks, impede water flow or adversely alter the waterway (City of Winnipeg, 2001). The area regulated by this by-law extends two hundred and fifty feet on either side of Omand's Creek. On these privately owned lands, bank stabilization has been achieved by re-grading the land and by the installation of buried rock caissons. Private landowners are strongly encouraged by the City of Winnipeg and by the Friends of Omand's Creek to plant native vegetation along the banks of creek (personal communication with R. Geeves, May 5, 2001). These landowners have complied with these wishes.

Continued urban development surrounding Omand's Creek will likely lead to increasingly frequent peak flows of longer duration. This will undoubtedly further test the resilience of the creek as both a functioning drainage system and as an important riparian corridor. Past disturbance of the urban reach of Omand's Creek have led to degradation of aquatic, fish and riparian wildlife habitat. The recreational values that have been lost due to the degradation of this habitat must also be considered.

From Notre Dame Avenue to the Assiniboine River there are 32 stormwater outfalls that drain into the creek. Twenty-nine of these outfalls lie within the 3.3km length of the creek that runs from Notre Dame Avenue to Rapelje Avenue. Of the 32 outfalls that drain into the creek, 22 of these enter the creek from the west (City of Winnipeg, 2001).

The downstream reach of Omand's Creek is contained within the Tylehurst Combined Sewer District. Running north from Notre Dame Avenue to the Assiniboine River, this district is bound by the CPR tracks to the east while its western edge lies between St. James and Madison Avenues. This area contains 263 ha of land, 153 ha of which drain into combined sewers. The remaining 110 ha are fed into the Assiniboine River and into Omand's Creek. Fifty percent of this district is made up of commercial property, thirty-three percent is light industrial, thirteen percent is open space and four percent is residential.

Secondary waterways such as Bunn's, Omand's, Truro and Sturgeon Creeks collectively comprise approximately 30 km of creek bank footage within the City of Winnipeg (City of Winnipeg, 2000). Smaller in scale than primary waterways, their typical bank height is less than 6 meters while typical channel widths are less than 10 meters (City of Winnipeg, 2000). Approximately 60% of these creek banks have been altered by urbanization (City of Winnipeg, 2000). Banks that have a uniform gradient and retrogression slope not less than 9H: 1V are considered representative of stable bank slopes that are capable of efficient drainage (City of Winnipeg, 2000). Stepped banks that have resulted from slumping and bank failure can be readily found along these creeks (City of Winnipeg, 2001).

Of the seven-kilometer stretch of Omand's Creek that runs from the Assiniboine River to Brookside Cemetery, 2,920 meters are in need of stabilization. To further illustrate extent of bank instability along Omand's Creek, Bunn's Creek and Sturgeon Creek require a mere 130 and 120 meters of bank stabilization respectively (City of Winnipeg, 2000).

The west side of Omand's Creek from St. Matthews Avenue to Saskatchewan Avenue and adjacent to Empress Street is in extremely poor condition. This slumping currently jeopardizes the structural integrity of Empress Street on the west side of the creek. With each successive season the creek bank continues to deteriorate. The costs associated with this neglect will continue to accrue. Using both engineered and bio-engineered stabilization methods, the total cost to stabilize the deteriorated banks of Omands Creek has been estimated at $2,330,000 (City of Winnipeg, 2000).

By replanting the creek bed with native riparian plant species, various community groups have worked in conjunction with the Friends of Omand's Creek toward reestablishing healthy riparian habitat along the creek. All levels of government have contributed their financial support to these community initiatives. The combined value of these efforts is enormous (personal communication with R. Geeves, May 5, 2001).

Future projects that are to take place along the downstream stretch of Omand's Creek include the continued naturalization of the creek banks, and the installation of ten riffle structures in an effort enhance aquatic and fish habitat

(Andrews, 1999). Several bank stabilization projects are soon to be undertaken by private landowners on the east side of the creek (personal communication with R. Geeves, May 5, 2001). Four portions of Omand's Creek have been targeted for restoration. These include Omand's Park at the Assiniboine River outlet, the land adjacent to the creek and neighboring Rae & Jerry's restaurant, and an east-west stretch of the creek between St. James Street and Dublin Avenue ("Paddling", 2001)

4.7 Site ecology

Local biologist and area resident Doug Collicut (1994) summarizes plant species along a portion of Omand's Creek that runs 250m north from Portage Avenue. This 1.7 ha. zone has remained undisturbed for many years. As such, this plot of land is an appropriate indication of the plant species that can still be found along the creek from Rapelje Avenue north to Sargent Avenue.

> This area supports a variety of plant communities. Near the water's edge, prairie cord grass, cattails, sandbar and pussy willows, and various sedges dominate. Higher up the banks a grassland community dominates. It consists of smooth brome, quack grass, Kentucky bluegrass, and a variety of native prairie grasses such as big bluestem, green needle grass and spear grass with various forbs including sweet clovers, Canada thistle, graceful goldenrod, crocus, and yellow lady's slipper. Dense patches of snowberry occur throughout this area and there are small stands of young Manitoba maple, cottonwood and other trees scattered throughout.
>
> (Colliucut, 1994)

Collicut also notes some of the fauna found in the area. Species including Canadian Toad, Leopard Frog, Wood Frog, Red-Sided and Western Plains garter snakes, Richardson's Ground Squirrel, Beaver, Muskrat, Meadow Vole and many bird species (Stadnyk, 1999). Creek Chub and Brook Stickleback are the only two fish species recorded by Collicut, however there have been reports of White Sucker being caught by anglers in Bluestem Park (Stadnyk, 1999).

North of St. Matthews Avenue the creek bed is dominated by Kentucky blue grass. Cattails can be found along much of the creek while red osier dogwood and several varieties of willows can also be found. The Friends of Omand's Creek are actively encouraging property owners to plant native riparian species along their respective portions of the creek. With each passing season and through continued community involvement, the creek is slowly being returned to its former glory as a diverse ecological community.

4.8 Public perception of Omand's Creek

Stadnyk (1999) notes that the public's perception of Omand's Creek is mixed.

> Commercial and industrial developers generally see the creek as what it was built for – a utilitarian drainage ditch which takes it's water away fast and efficiently. These businesses commonly build outfalls into the creek. Others see the creek from its working and potential as a natural habitat and recreation resource, where riparian plant communities and wildlife may and do thrive.
> (Stadnyk, 1999, p. 24)

Activists and community groups, such as the Friends of Omand's Creek, have heralded the importance of the creek and are continually working towards its enhancement. As commercial/retail development has continued to encroach its banks, Omand's Creek has become the focus of debate. As noted by Stadnyk (1999) if development continues without the concerns of protective organizations and individuals being heard, "Incremental development along the waterway would see it gradually disappear through culverts and sewers, as did Colony Creek" (p. 25). This has not necessarily been the case.

Despite the fact that the new commercial developments adjacent Omand's Creek have been the focus of media scrutiny and frequent public condemnation, the creek is growing healthier. The owners of the creek property have occasionally been cajoled into their respective roles as good corporate environmental citizens. Nevertheless, as each old industrial warehouse is removed and commercial redevelopment begins, a new stretch of creek becomes available for bank stabilization and restoration at the expense of the landowner (personal communication with R. Geeves, May 5, 2001).

The huge amount of garbage that is pulled out of Omand's Creek every spring suggests that most Winnipeg citizens view the creek as an extemporaneous landfill. Shopping carts, wooden pallets, cement bricks, chain link fencing, plastic bags, and packing foam are a few of the items that abound inside the creek. This garbage is in the creek because many people don't view the creek as an important waterway. Despite the misuse of the creek over the past half-century, things are looking up. A condominium complex was proposed for this site in 1984, in the mid 1990s a baseball stadium was proposed for this site. If constructed, these projects would have redirected the creek and placed a greater portion of it into underground culverts. That such proposals have consistently been defeated suggests that the City of Winnipeg and its citizens have come to recognize the heritage and value of this abused waterway.

As beautification and naturalization projects continue, citizens are beginning to take a second look at the creek and see it from an entirely new perspective. As the true character of Omand's Creek emerges, so does its potential as a valuable source of public recreation. Bartley Kives, a reporter for the Winnipeg Free Press who recently paddled the entire length the creek, observed that, "beyond the deer, ducks and muskrats was the presence of a hidden world...Blasted by spring meltwater, metal culverts looked clean enough to eat off. The remains of wooden bridges spoke of more than 130 years of Prairie settlement ("Paddling", 2001, B3). Kives' article exemplifies the metamorphosis of public opinion that is encouraging people to rediscover the rich history and natural heritage of Omand's Creek.

4.9 Commercial growth around Omand's Creek

The location of this site makes it ideal for commercial retail and commercial entertainment activity. Over the past several decades, urban growth has led this site to become less of a suburban fringe. As industrial manufacturers have moved from the area to larger sites, commercial businesses have moved into this area to take advantage of the centrally located land (Stadnyk, 1999). Stadnyk notes that these post-industrial lands are typically less expensive than locating downtown and thus, more attractive to developers.

> The expansion of Polo Park Mall in the 1980s, to firmly establish itself as Winnipeg's largest shopping centre also served to influence intensified development of the surrounding area. That is, it attracted other commercial peripheral development – restaurants, retail chains and superstores that were geared to compete with the mall for the consumer dollar. Industries have given way in as recent as the last five years to such large corporations as Winners, The Home Depot, Revy's and Chapters, and the development continues to be voracious.
>
> (Stadnyk, 1999, p. 22)

One of the problems the City of Winnipeg has experienced with respect to controlling the development of this land stems from its zoning regulations. In the transition from predominantly industrial use to commercial use, re-zoning of the site was not required. Instead, occasional zoning variances were required. Without the requirement of re-zoning hearings in which the City of Winnipeg could hold developers accountable for such issues as site-runoff and traffic congestion, City officials had very little control over the development of this land (personal communication with J. East-Ming, March 15, 2001). As commercial growth continues within this area, the problems associated with unchecked development will likely plague this area well into the future.

4.10 Site selection criteria

A portion of this study focuses on a 43-acere site that is adjacent to Omand's Creek. As a waterway, Omand's Creek serves as an important source of habitat for aquatic, avian and terrestrial species. The study site has experienced a recent influx of new commercial development. As a result, all buildings on the site are either new buildings or recent retrofits. It is conceivable that the structures found on this site could have utilized extensive green roofing had the conditions, motivation and interest to do so existed.

The site selected for the purpose of this research is zoned as both M2 industrial and C2 commercial. It is located in the St. James area of Winnipeg. In selecting the study site, the following criteria were established.

- Study properties must be adjacent to Omand's Creek
- Each study property must contain buildings that have been constructed or altered within the past ten years
- The study site must make up a single contiguous stretch that is at least one kilometer in length

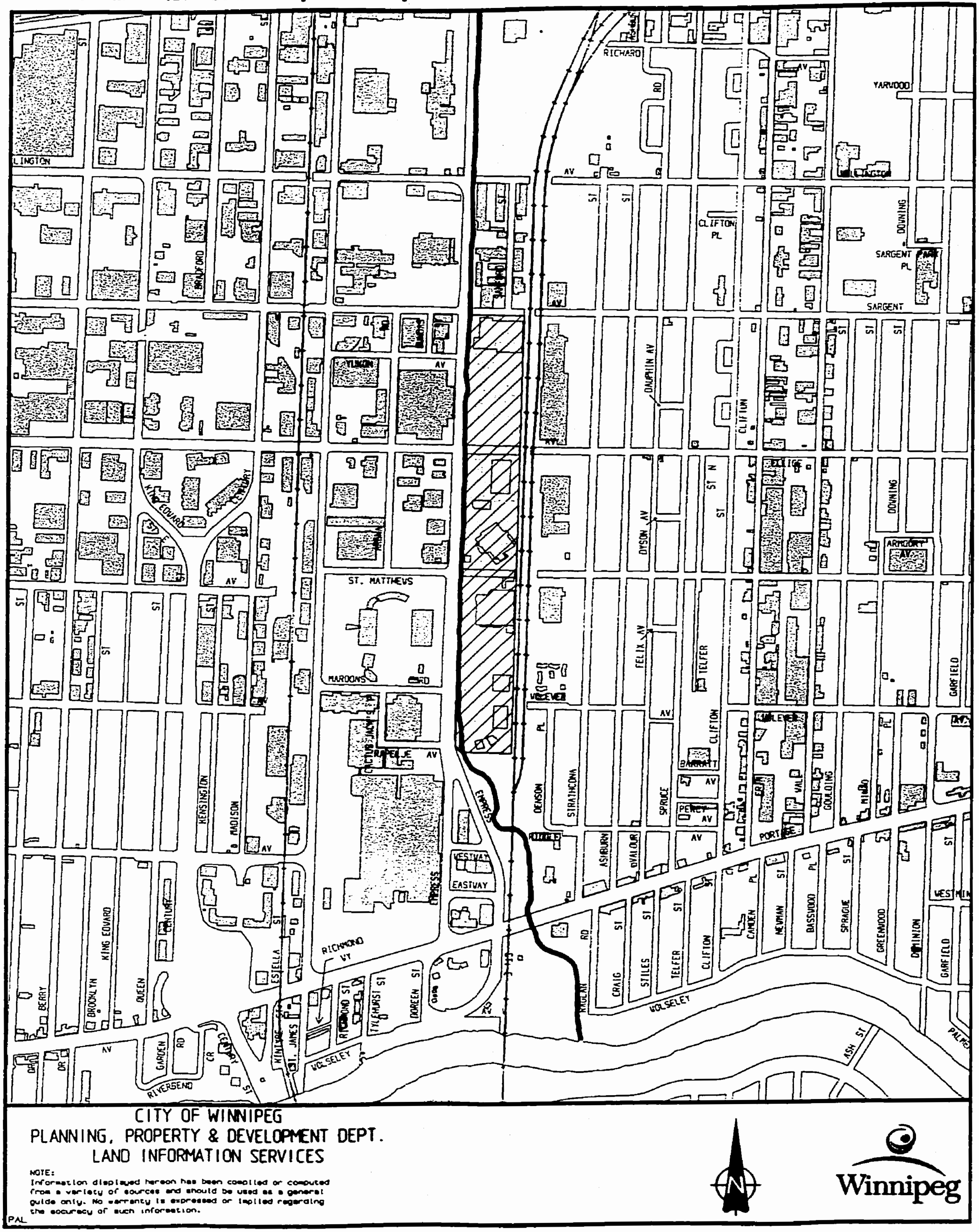
On reviewing the site using the above criteria, a 1.23km stretch of property was selected. Bluestem Park bounds the southern end of the site, while Sargent Avenue bounds the northern end. The site is bordered by the CPR rail tracks on the east and by Empress Street to the west. Figure 4.10 on page 177 illustrates the extent and surrounding context of the study site (hatched area indicates the study site).

4.11 Site description

The study site, located between Sargent Ave. and Rapleje Avenue, is 1.23 km long, is 103m wide at its narrowest point and 140m at its widest point. It covers an area of approximately 43.06 acres (17.42 ha.). For the purposes of this description, the site has been divided into three zones (see Illustration 4.11, page 180). Zone One runs from Sargent Avenue to Ellice Avenue. Zone Two runs from Ellice Avenue to St. Matthews Avenue. Zone Three runs from St. Matthews Avenue to Bluestem Park. Omand's Creek runs along the western edge of these zones, while the CPR rail line borders the east side of each zone.

Unless otherwise stated, the site information provided has been obtained through site visits, digital orthophotos, the Friends of Omand's Creek, or through the City of Winnipeg Planning Property and Development Department, Department of Water and Waste and the Naturalist Services branch of the Community Services Department. Refer to Tables 4.9 (a) and (b) for a summary of the surface materials and drainage conditions that exist on this site. In order to simplify calculations that will be made in Chapter Five, surface areas are represented in square feet and acres. Site data can be viewed in Appendix B.

Illustration 4.10 – Context Map of the Study Site



4.11.1 Zone One - Sargent Avenue to Ellice Avenue

At the intersection of Sargent Avenue and Empress Street, the newly constructed Wal-Mart retail store can be found. This project was completed in the winter of 2001. Zoned as M2 industrial, this new building replaced four older industrial buildings. The flat-roofed Wal-Mart building covers an area of 124,600sq.ft. and its adjacent garden centre covers an area of 13,540sq.ft. It is important to note that 82,340sq.ft. the roof area and loading docks at the rear the Wal-Mart building flow into the Tylehurst combined sewer. There are two drainage outfalls running into Omand's Creek from this property. This site is accessed via a newly constructed bridge off of Empress St. as well as an access road off of Ellice Avenue.

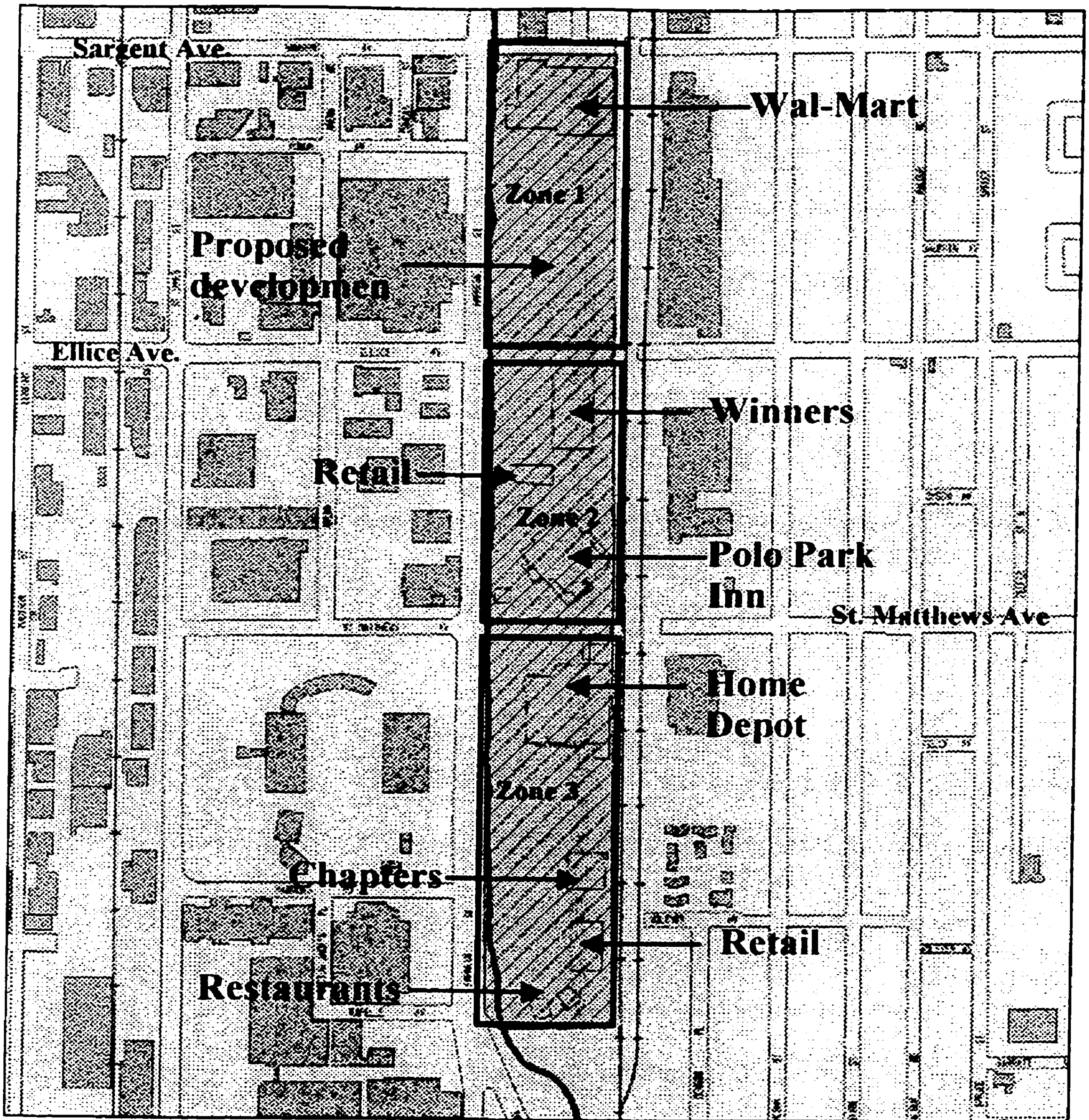
The Wal-Mart parking lot and other paved surfaces cover an area of 118,627sq.ft. Although 475 parking stalls are required to support this development, 588 parking stalls have been provided. The runoff from this site is directed into Omand's Creek. The developer has installed an oil/water separator in order to mitigate the impact of polluted runoff from the parking lot. With a combined area of 2,522sq.ft, twelve planted islands have been constructed within the parking lot.

The property that runs from south edge of the Wal-Mart parking lot to Ellice Avenue is currently vacant (with the exception of a fire access road that bisects the property). The two industrial buildings that once stood on this property have recently been removed. Zoned as M2 industrial, preliminary plans for the development of this site have been completed. Calculations for this portion of the study site use the preliminary plans that have been submitted to the City of Winnipeg Planning Property and Development Department. This land will contain four commercial properties with a combined roof area totaling 40,000sq.ft. The combined total of all paved surfaces on this site is 183,229sq.ft. The parking lot will contain 8 planted islands with a combined area of 8,440sq.ft. Not all of the land from this commercial development drains into Omand's Creek, 37,090sq.ft. of property adjacent to Ellice Avenue drains into the combined sewer. Zone One contains over 80,000sq.ft. of creek bed, two-thirds of which have an integrated pedestrian trail.

4.11.2 Zone Two - Ellice Avenue to St. Matthews Avenue

This portion of the study site is zoned as M2 Industrial. The properties constructed on this site include a Winners retail outlet, a multi-tenant commercial outlet, the newly renovated Polo Park Inn and a small stand-alone Beer Vendor. This property can be accessed off of both Ellice and St. Matthews Avenues. A CPR rail line once bisected this site and crossed over the creek via a rail bridge that was removed in 2000. The multi-tenant unit that currently houses Tootsies Family Shoe Market and Penningtons Superstore has since been constructed over the old rail bed. There are two drainage outfalls that drain into Omand's Creek from this site and a total of seven catch basins located throughout. The six-story Polo Park Inn has undergone recent renovations. The data gathered for this building and its surrounding parking lot reflects these changes. The combined roof area coverage by the structures in Zone Two equals 141,241sq.ft. The total asphalt surfacing within this zone is 310,687sq.ft. There are 13 planted islands that have been incorporated into the newly

Illustration 4.11 Buildings on the Study Site



(City of Winnipeg Land Information Services, 2001) renovated parking lot which total 4,887sq.ft. The creek bed that runs along the west side of this property is 73,270sq.ft. There are two areas within this zone that drain into the Tylehurst combined sewer which cover an area of 145,855sq.ft,

4.11.3 Zone Three - St. Matthews Avenue to Bluestem Park

From St. Mathews Avenue to Bluestem Park, the land is zoned as C2 commercial. The buildings on this site include The Home Depot, Chapters Bookstore, Sportmart, Montana's Cookhouse, and Kelsey's restaurant. This portion of the site was once home to the Winnipeg Velodrome. The Home Depot outlet was constructed in 1997. The construction of Chapters Bookstore and the three other properties commenced in the fall of 1998. The creek bed that is adjacent to Zone Three from Rapleje Avenue to Maroons Road is owned by the City of Winnipeg. Prior to development taking place in this area, a portion of this creek bank was graded and stabilized using rock caissons. Although on City land, the cost of this stabilization project was borne by the developer (personal communication with R. Geeves, May 5, 2001). There is a crushed limestone path that runs along the creek from St. Matthews Avenue and into Bluestem Park. The creek banks are currently being replanted with native plants and prairie grasses.

The roof area of the Home Depot is 104,025sq.ft. The attached outdoor garden centre is 21,082sq.ft. The paved surfaces found on this site (i.e. parking stalls, access roads, loading docks and sidewalks) have a combined area of 274,634sq.ft. There are 20 planted islands/edge areas within this parking lot with a combined area of 10,377sq.ft. The planted islands contain a groundcover of pygmy caragana and are planted with a mix of green ash and amur cherry trees. The creek bed along the Home Depot has been stabilized and replanted with native species. There is a crushed limestone path that runs between the creek and the Home Depot property.

It is important to note that 170,000sq.ft. of the Home Depot site drains into the Tylehurst combined sewer system. As a result, the land to the north of the building and entire roof surface of the building does not drain into Omand's Creek.

The four buildings to the south of the Home Depot contain a cumulative roof area of 58,585sq.ft. There is 177,000sq.ft. of asphalt paving with parking to accommodate 418 automobiles. There are sixteen planted islands in the parking lot totaling 4,606sq.ft. 15,302sq.ft. of grass surround Montana's Cookhouse, Kelsey's Restaurant and their respective patio spaces. Two drainage outfalls run into the creek from this site, the site has and a total of seven catch basins (City of Winnipeg, 2000).

Table 4.11(a) Summary of Surface Materials

Description	*Zone 1 (acres)*	*Zone 2 (acres)*	*Zone 3 (acres)*	*Surface Total (acres)*
Roof surfaces (flat, gravel)	3.7791	3.2430	3.7336	10.7557
Concrete/asphalt/patio	7.2415	7.1334	10.4388	24.8137
Grass (5-10%slope, clay and silt loam)	1.7468	1.6823	1.3328	4.7619
Grass (no slope, clay and silt loam)	0.00	0.00	0.4131	0.4131
Crushed limestone (compacted)	0.0928	0.00	0.1205	0.2133
Planted islands in parking lots	1.6343	0.1134	0.3532	2.1009
SUM OF ALL SURFACES	**14.4945**	**12.1721**	**16.3920**	**43.0586**

Table 4.11(b) Comparison of Area Draining into Tylehurst Combined Sewer and Area Draining into Omand's Creek

Description	*Zone 1 (acres)*	*Zone 2 (acres)*	*Zone 3 (acres)*	*Total (acres)*
Area draining into combined sewer system (acres)	2.7421	3.3488	3.9032	**9.9941**
% Of area draining into combined sewer system	**%18**	**%28**	**%24**	**%23**
Area draining into Creek	11.7524	8.8233	12.4888	**33.0645**
% Of area draining into Creek	**%82**	**%72**	**76%**	**%77**

4.12 Chapter Summary

This chapter has shown that Omand's Creek has been greatly influenced by the natural and social history of this province. Indeed, it is more than a creek; it is a landmark that has shaped our history from pre-settlement times to the present. It is very obvious that many worthwhile projects are being undertaken in order to ensure that the future health of Omand's Creek. Bank stabilization and naturalization projects have been completed, future projects are in the planning and attitudes regarding the creek are changing. Despite this the question remains, how will the increases in runoff flowing from newly developed sites affect the creek? Orthographic photos suggest that industrial properties that preclude the present-day development contained fewer non-porous surface areas. Chapter Five will use the data gathered in this chapter to determine the present-day rates of runoff from this site. It will then determine if extensive green roofing could play a role in managing the stormwater runoff resulting from this site.

Chapter Five – An Analysis of Site Runoff under Three Land Use Scenarios

Urbanization interrupts the hydrologic cycle by compacting the soils and by sealing the surface of the impervious surfaces. This shifts runoff away from its natural subsurface path to the surface. The higher the percentage of impermeable surfacing and surface compaction that exists a site, the greater the amount of runoff flowing from that site will be. The costs associated with controlling runoff are therefore directly related to the type of surfacing materials found on the site. This chapter will use the data gathered in Chapter Four to quantify the amount of runoff from the study site and estimate the costs associated with controlling this runoff.

5.1 Objectives

The objectives of this chapter are threefold. Firstly this chapter makes use of the data collected in Chapter Four to quantify the differences in runoff resulting from the study suite under three different storm intensities and three different land use scenarios. By comparing the extensive green roofing scenario with the existing conditions and the pre-development scenarios, conclusions are drawn with respect to the potential effectiveness of extensive green roofing in mitigating stormwater runoff from the study site.

Next, by hypothetically increasing the amount of permeable surfacing material on the study site, the cost savings that might be realized through less capital intense sub-grade drainage systems are calculated. Converted to a percentage, these savings are projected against current estimates of what both the private sector and the City of

Winnipeg collectively spend each year on the construction of land drainage infrastructure. Assuming the widespread use of green roofing in one scenario, and pre-development levels of runoff in another, the potential savings with respect to current citywide expenditures on land drainage infrastructure achievable by employing greater levels of permeable surfacing are calculated.

Last, assuming local conditions, the cost of green roof installation per cubic foot of water retained by the roof is calculated. This figure is then compared to local estimates of the cost per cubic foot of water retention using both sub-grade retention basins and stormwater retention ponds.

5.2 Methods

The methods used in performing the calculations contained within this chapter are discussed within the two following sub-sections. The first sub-section will discuss the calculations used to estimate stormwater runoff. The second sub-section will discuss the methods used to calculate the economic valuation of savings to sub-grade infrastructure on a citywide scale, and to compare the cost of green roofing per cubic foot of water retention to that of sub-grade stormwater storage tanks and stormwater retention ponds.

5.2.1 The Rational Method of stormwater runoff calculation

The data collected in Chapter Four have been used to calculate the runoff from each of the three zones within the study site. These data can be viewed in Appendix B. The storm intensities that have been used in these calculations include a five-year storm, a twenty-year storm and a fifty-year storm. The resulting runoff figures for each respective zone are then combined to give an overall estimate of the runoff flowing from the entire site under each respective storm type.

Kulching's Rational Formula was used to perform all runoff calculations within this chapter. The Rational Formula was introduced as a means for estimating peak discharges of runoff from rainfall in urban areas (Sykes, 1998). It remains one of the most widely used and universally accepted methods of computing stormwater runoff.

The formula for the Rational Method is:

$$Q = CiA$$

Where:

Q = Peak discharge in runoff in cubic feet per second (cfs.)

C = Runoff coefficient (the ratio of runoff to rainfall for a given surface type)

i = Rainfall intensity at the time of concentration (in inches per hour)

A = Watershed area (acres)

The coefficients for runoff used within these calculations were found in several different sources. The coefficients and their respective sources used are as follows:

- Concrete/Asphalt/Patio = 0.95 (Munson, 1974)
- Grass (5-10% slope, clay and silt loam) = 0.36 (Marsh, 1997)
- Grass (no slope, clay and silt loam) = 0.50(Marsh, 1997)
- Crushed limestone (compacted) = 0.70 (Munson, 1974)

- Planted areas (flat, treed, clay and silt loam) = 0.30 (Marsh, 1997)
- Rooftops (flat, gravel) = 0.95 (Munson, 1974)
- Extensive green roof (planted) = 0.40 (Durr, 1995)

For each storm scenario, the rainfall intensity used within the Rational Formula were obtained from Munson's (1974) calculations of typical probability curves for rainfall in the North Central United States (p.110). These figures are as follows:

- 5-year storm = 1.65 inches of rainfall per hour
- 20-year storm = 2.2 inches of rainfall per hour
- 50-year storm = 2.5 inches of rainfall per hour

Using the data gathered in Chapter Four (Appendix B), assuming 5, 20 and 50-year storms of one hour in duration, the following calculations have been completed for each of the three zones within the study site using the Rational Formula. The resulting preliminary calculations were recorded in tabular format and can be reviewed in Appendix C.

1. The total area of the each zone is calculated and the area/percentage of each zone flowing into the combined sewer system and into Omand's Creek is determined.

2. The total runoff in each zone under pre-development conditions is calculated.

3. The runoff resulting from surfaces at grade (i.e. excluding rooftop areas) is calculated.

4. The runoff from existing rooftop surfaces and rooftop runoff under the scenario of extensive green roofing is calculated.

5. Runoff under existing conditions, green roofed conditions and pre-development conditions are tabulated and compared for each zone.

6. The amount of stormwater flowing from each zone and into bothe the Tylehurst Combined Sewer System and into Omand's Creek is determined.

The preliminary calculations preformed for each zone are used within this chapter to summarize the site-wide implications of employing alternate surfacing materials on the site. These calculations have been tabulated for discussed within this chapter. The site-wide calculations made within this chapter include the following. Again, these calculations assume 5, 20 and 50-year storms of one hour in duration and are based on the preliminary zone calculations found in Appendix C.

1. The total runoff from the entire study site is calculated under the existing conditions, green roofed conditions and pre-development conditions [see Tables 5.5(a) to 5.5(c)].

2. A comparison of the runoff from all existing rooftop surfaces is compared to the same rooftop area under green roofed conditions [see Table 5.5(d)].

3. These results of the above calculations are then used to identify the amount of stormwater runoff that would flow into the Tylehurst Combined Sewer System and into Omand's Creek under each respective land-use scenario [see Tables 5.5(e) to 5.5(g)].

4. A comparison of the percentage of all runoff flowing from the entire site and into both the combined sewer system and Omand's Creek is made for each land-use scenario [see Table 5.5(h)].

5.2.2 Valuation of potential savings to land-drainage infrastructure

Using the site-wide runoff results for a 20-year storm of one hour in duration, runoff values in cubic feet per-second are determined using the existing conditions, projected green roofed conditions and projected pre-development conditions. The runoff values for each land-use condition are subsequently used to determine the requisite pipe diameter for site drainage using Manning's Formula for channel flow. The flow of water in open channels is a function of velocity and the cross-sectional area of flow. Velocity is a function of slope, surface roughness and cross-sectional shape (Sykes, 1998).

Using Manning's Formula and assuming a 20-year storm of one-hour in duration, the following calculations are made for each zone under the three land-use conditions as outlined earlier.

1. By assuming the use of concrete pipe sloped for drainage at a self-cleaning velocity of 2½ feet per-second, the requisite pipe diameters are determined using Manning's table found in Munson (1974, p.110) [Table 5.5(e)].

Upon the derivation of the appropriate pipe diameters for each zone and under each of the three land-use conditions, the following calculations were made within sub-sections 5.5.4 to 5.5.7 of this study.

1. The per-meter costs of installation for each pipe diameter (including excavation to a depth of 12 ft., backfill, and bedding material) were determined. The per-meter cost of concrete pipe installation for each pipe diameter can be found in Table 5.5(i).

2. The values derived in Table 5.5(i) are used to determine the average per-meter cost of land drainage infrastructure under each land-use scenario for the entire study site [Table 5.5(j)].

3. The potential savings to land drainage infrastructure under each land-use condition is calculated as a percentage [Table 5.5(k)].

4. The projected per-annum spending by both the private sector and by the City of Winnipeg was determined (personal communication with A. Nagy, June 19, 2001).

5. The potential savings to land drainage infrastructure within the site is projected onto the annual spending on land drainage infrastructure within the City of Winnipeg. The potential per-annum savings achievable by increasing the permeability of surfacing materials is determined [Table 5.5(l)].

Sub-section 5.5.8 of this chapter uses methods found in Kuhn (1999) to achieve the following.

1. The annual volume of water retention per square foot of green roofing is calculated.

2. The annual cost per cubic foot of water retention using green roofing is calculated.

3. The cost per cubic foot of water retention using green roofing was then compared to locally available cost estimates (per cubic foot) of retaining runoff using sub-grade storage tanks and stormwater retention ponds.

5.4 Assumptions and Limitations

Sykes (1998, p. 23) notes that several assumptions are intrinsic to the Rational Formula. These assumptions are as follows:

1. Rainfall intensity is uniform throughout the watershed and unvarying throughout the duration of the storm.

2. Peak discharge occurs at the time of concentration (i.e. it is still raining at the time of concentration).

3. Duration of rainfall is equal to the time of concentration (therefore the storm is of sufficient duration to allow runoff to arrive at the outlet from all parts of the watershed simultaneously).

4. Time of concentration includes time for satisfaction of initial abstractions, and should never be considered to be less than six minutes (i.e. time of concentration includes that time that it takes the runoff to flow overland to the drainage inlet and through the conduit to the outfall).

The coefficient for runoff used for extensive green roofing has been sourced from a German technical publication. This was the only source of information that was found to indicate a previously researched coefficient for runoff for extensive green roofing. Observations by professionals have indicated that a coefficient of 0.40

is a very conservative figure and that it may be as low as 0.25 depending on the type and thickness of the substrate and vegetation used (personal communication with K. Scholtz-Barth, May 29, 2001). Kuhn (1999) expresses that the coefficient for runoff from extensive green roofing can be as low as 0.15. Bovin & Challis (1998) acknowledge that green roofs installed in northern climates require thicker substrates than those installed in more temperate regions. As a result of the thicker substrates, roofs located in northern climates should be able to retain more water than green roofs in warmer regions.

Previously completed green roof runoff calculations have utilized runoff coefficients derived by anecdotal observations rather than measurements. Although such figures are indeed valuable, a coefficient that has been determined through quantitative measurements of extensive green rooftop runoff will be utilized for the purpose of this study.

Although the coefficient for runoff used within this study is a conservative figure, it must be acknowledged the calculations made within this study assume that the substrate is unsaturated prior to the calculated storm event. In reality, this wouldn't necessarily be the case. Because of the frequency of intense summer rainstorms experienced in Winnipeg City, it is highly probable that the substrate would be partially saturated prior to the rainfall event. To use a lower coefficient for runoff might be misleading.

One of the land-use scenarios used in this study assumes a coefficient of runoff that replicates the site conditions prior to development. The results derived under this scenario are to be used only as a benchmark from which to compare the gains made under the scenario of the site-wide use of extensive green roofing. This study does not purport that achieving pre-development rates of runoff is attainable. Rather, using this scenario indicates the potential savings that could be achieved under the most ideal circumstances.

In calculating the runoff from the site and flowing into Omand's Creek and the Tylehurst Combine Sewer System, the calculations assume that the runoff flowing into these two systems is received in equal proportions from all parts of the site. However, surveys indicate that runoff that is directed into the combined sewer system flow from locations that contain a high proportion of roof area (personal communication with A. Nagy, April 19, 2001).

It must be recognized that the calculations made with respect to the financial valuations of the potential savings to citywide land drainage infrastructure do not represent the true savings that would accrue through the use of a higher percentage of permeable surfacing materials. Rather, these figures demonstrate the proportional savings that might be realized through the use of more permeable surfacing materials and are limited to the 20-year storm scenario utilized within the calculations. Because the land drainage infrastructure installation costs do not account for catch basins, manholes, cisterns or inlet control devices, these figures are very conservative estimates. These valuations do not include maintenance costs.

The calculations in sub-section 5.5.7 of this chapter do not take into account the installation costs of green roofing. It is likely that the savings to sub-grade infrastructure achieved through the use of green roofing would be absorbed by the high installation costs associated of the green roofing. Sub-section 5.5.8 will address the issue of green roof installation costs.

The design of a stormwater drainage system for this site would necessitate the calculation of pipe lengths and the pattern of water flow from the site. It would also require the calculation of the various pipe sizes required (according to their location within the conveyance system), the invert elevations of pipe connections, and the location of all catch basins. Owing to its inherent complexity, the design of such a system does not fall within the scope of this research.

Neither maintenance costs nor the cost of acquiring land for retention ponds are considered in sub-section 5.5.8. Likewise, the cost of the sub-grade stormwater storage tanks used in these calculations is for robust concrete tanks in which the concrete has been poured on site rater than pre-fabricated (personal communication with A. Nagy, June 27, 2001).

In using the methods found in Kuhn (1999) in sub-section 5.5.8 of this chapter, the supply and installation costs used include the cost of a waterproofing membrane and assume the use of upper-end materials and components. For simplification, the systems discussed assume a conservative ten-year lifespan. This assumption highlights the conflict between the ecological design solutions and current models of financial valuation. Methods of valuation that would better reflect the true life-cycle cost (and resulting long-term financial gains) of more durable building techniques and materials would be very beneficial.

5.5 Findings

5.5.1 Runoff from the study site under three dissimilar land-use conditions

Tables 5.5(a), 5.5(b) and 5.5(c) demonstrate the difference in surface runoff flowing from the site under the existing conditions, under green roofed conditions and under pre-development conditions.

Table 5.5 (a) - Runoff from Study Site under Existing Conditions (cfs.)

Storm Scenario	*Zone 1 runoff*	*Zone 2 runoff*	*Zone 3 runoff*	**Total runoff**
5-year storm	19.23	17.89	23.65	**60.77**
20-year storm	25.64	23.04	31.57	**80.25**
50-year storm	29.13	26.19	35.85	**91.17**

Table 5.5 (b) Runoff from Study Site under Green Roofed Conditions (cfs.)

Storm Scenario	*Zone 1 runoff*	*Zone 2 runoff*	*Zone 3 runoff*	**Total runoff**	**% reduction from Table 5.5 (a)**
5-year storm	15.80	14.32	20.26	**50.38**	**17%**
20-year storm	21.07	19.12	26.23	**66.42**	**17%**
50-year storm	23.93	21.73	30.71	**76.37**	**16%**

When compared to the existing conditions, it can be observed in Table 5.5(b) that under each storm scenario, green roofing would achieve a 16-17% reduction in stormwater flow from this site. Depending on the storm intensity, this means a reduction in flow of between 10 and 15 cubic feet per second from the study site.

Table 5.5 (c) Runoff from Study Site under Pre-development Conditions (cfs.)

Storm Scenario	*Zone 1 runoff*	*Zone 2 runoff*	*Zone 3 runoff*	**Total runoff**	**% reduction from Table 5.5 (a)**	**% reduction from Table 5.5 (b)**
5-year storm	11.56	9.65	13.21	**34.42**	**43%**	**32%**
20-year storm	15.40	12.87	17.63	**45.90**	**43%**	**31%**
50-year storm	17.50	14.82	20.02	**52.34**	**43%**	**31%**

Under pre-development conditions, it can be observed in Table 5.5(c) that a 43% reduction from the existing conditions would be realized. This reduction is 32% greater than that which is achievable through the use of extensive green roofing. If pre –development rates of runoff were reestablished on this site, runoff would be reduced by 26-39 cubic feet per second. This points to the need for a more balanced approach toward how we treat all surfaces.

5.5.2 A site-wide comparison of runoff from standard roofing and green roofing

In isolating the rooftop surfaces and disregarding the surfaces surrounding the buildings on the study site, it is possible to compare the water retention capabilities of green roofing on the study site and compare these with the existing flat roofs. Table 5.5(d) demonstrates 58% reduction in roof runoff under the scenario of the widespread use of extensive green roofing on the study site. Depending on the intensity of the storm, savings in runoff of between 10 - 15 cubic feet per second could be attributed to the use of extensive green roofs on this site.

Table 5.5 (d) - A Comparison of Runoff from Standard Roof Surfaces and Proposed Green Roof Surfaces on the Study Site (all figures in cfs.)

	Standard Roofing				Green Roofing				
Storm Scenario	*Zone 1 runoff*	*Zone 2 runoff*	*Zone 3 runoff*	**Total runoff**	*Zone 1 runoff*	*Zone 2 runoff*	*Zone 3 runoff*	**Total runoff**	**% runoff reduction**
5-year storm	5.92	5.08	5.85	**16.85**	2.49	2.14	2.46	**7.09**	**58**
20-year storm	7.90	6.77	7.80	**22.47**	3.33	2.85	3.29	**9.47**	**58**
50-year storm	8.98	7.70	8.87	**25.55**	3.78	3.24	3.73	**10.75**	**58**

5.5.3 Examination of the study site under dissimilar land-use conditions with an identification of the terminus of stormwater flow

Using the three different storm scenarios that are considered within this study, the amount of stormwater flowing off of the study site and into both Omand's Creek and into the Tylehurst Combined Sewer System is identified. Tables 5.5(e) to 5.5(g) indicate the amount rainwater flowing into both of these systems under the existing land use conditions, under green roofed conditions, and under pre-development conditions.

Table 5.5 (e) - Runoff from Study Site under Existing Conditions into Omand's Creek and into Combined Sewer System (all figures in cfs.)

Storm	*Zone 1 runoff into Creek*	*Zone 2 runoff into Creek*	*Zone 3 runoff into Creek*	**Total runoff into Creek**	*Zone 1 runoff into CSS*	*Zone 2 runoff into CSS*	*Zone 3 runoff into CSS*	**Total runoff into CSS**
5-year storm	15.77	12.88	17.97	**46.62**	3.47	5.00	5.68	**14.15**
20-year storm	21.02	16.58	24.00	**61.60**	4.62	6.45	7.57	**18.64**
50-year storm	23.89	18.86	27.25	**70.00**	5.24	7.33	11.25	**23.82**

Tables 5.5(f) and 5.5(g) illustrate that the use of extensive green roofs on the study site would reduce stormwater runoff into Omand's Creek by between 17 – 21% depending on the storm scenario. Green roofs would reduce the runoff flowing into the combined sewer system by 13 – 17%. By achieving levels of pervious surfacing

that approach pre-development conditions, runoff into Omand's Creek would be reduced by 43% and runoff into the combined sewer system would be reduced from between 43 – 50%. Table 5.5(h) provides a summary of these calculations.

Table 5.5 (f) - Runoff from Study Site under Green Roofed Conditions into Omand's Creek and into Combined Sewer System (all figures in cfs.)

Storm	*Zone 1 runoff into Creek*	*Zone 2 runoff into Creek*	*Zone 3 runoff into Creek*	**Total runoff into Creek**	*Zone 1 runoff into CSS*	*Zone 2 runoff into CSS*	*Zone 3 runoff into CSS*	**Total runoff into CSS**
5-year storm	12.96	10.31	15.40	**38.67**	2.84	4.01	4.86	**11.71**
20-year storm	17.28	13.77	19.93	**50.98**	3.79	5.35	6.30	**15.44**
50-year storm	16.62	15.64	23.34	**55.60**	7.31	6.09	7.37	**20.77**

Table 5.5 (g) - Runoff from Study Site under Pre-development Conditions into Omand's Creek and into Combined Sewer System (all figures in cfs.)

Storm	*Zone 1 runoff into Creek*	*Zone 2 runoff into Creek*	*Zone 3 runoff into Creek*	**Total runoff into Creek**	*Zone 1 runoff into CSS*	*Zone 2 runoff into CSS*	*Zone 3 runoff into CSS*	**Total runoff into CSS**
5-year storm	9.48	6.95	10.04	**26.47**	2.08	2.7	3.17	**7.95**
20-year storm	12.63	9.27	13.40	**35.30**	2.77	3.6	4.23	**10.60**
50-year storm	14.35	10.67	15.22	**40.25**	3.15	4.15	4.80	**12.10**

Table 5.5 (h) A Comparison of Runoff from the Study Site under Three Land-use Scenarios (cfs.)

Storm	***Existing site runoff into Creek***	**Green Roofed runoff into Creek**	**% Change from Existing**	**Pre-development runoff into Creek**	**% Change from Existing**	***Existing site runoff into CSS***	**Green Roofed runoff into CSS**	**% Change from Existing**	**Pre-development runoff into CSS**	**% Change from Existing**
5-yr storm	*46.62*	38.67	**17**	26.47	**43**	*14.15*	11.71	**17**	7.95	**44**
20-yr storm	*61.60*	50.98	**17**	35.30	**43**	*18.64*	15.44	**17**	10.60	**43**
50-yr storm	*70.00*	55.60	**21**	40.25	**43**	*23.82*	20.77	**13**	12.10	**50**

5.5.4 Comparison of drainage pipe diameters under three different land-use scenarios

By inputting the values for stormwater flow for a twenty year storm into the flow table derived by Manning's Formula (Munson, 1974, p.110), the pipe diameters required to convey water from each zone within the study site were determined Table 5.5(i). These values assume the use of concrete pipe flowing at a velocity of 2 ½ feet per second.

Table 5.5 (i) - Comparison of Drainage Pipe Diameters under Three Different Land Use Scenarios

Land Use (20-yr storm, 1-hr duration)	*Zone 1 runoff (cfs.)*	*Zone 1 required pipe diameter (inches)*	*Zone 2 runoff (cfs.)*	*Zone 2 required pipe diameter (inches)*	*Zone 3 runoff (cfs.)*	*Zone 3 required pipe diameter (inches)*
Existing condition	25.64	48	23.04	42	31.57	48
Green-roofed condition	21.07	42	19.12	36	26.23	48
Pre-development condition	15.40	30	12.87	30	17.63	36

5.5.5 Site-wide cost savings to infrastructure under three land-use scenarios

By consulting with a professional contractor experienced in the installation of land drainage infrastructure, cost estimates for each respective pipe size were determined (personal communication with Borland Construction, June 19, 2001). These cost estimates assume that pipes have been placed at a minimum depth of 12 feet and include the cost of excavation, bedding materials and backfill [see Table 5.5(j) on the following page].

Table 5.5 (j) - Comparison of Sewer Installation Costs under Three Different Land Use Scenarios assuming a 20-year Storm 1-hour in Duration

Land Use Scenario	*Zone 1 required pipe diameter (inches)*	*Zone 1 pipe installation cost (per meter)*	*Zone 2 required pipe diameter (inches)*	*Zone 2 pipe installation cost (per meter)*	*Zone 3 required pipe diameter (inches)*	*Zone 2 pipe installation cost (per meter)*
Existing condition	48	$630.00	42	$540.00	48	$630.00
Green-roofed condition	42	$540.00	36	$440.00	48	$630.00
Pre-development condition	30	$360.00	30	$360.00	36	$440.00

5.5.6 Projected citywide savings to sub-grade infrastructure achieved through the use of extensive green roofing.

The average cost of land-drainage infrastructure for each zone under post development conditions, green roofed conditions and pre-development conditions are calculated in Table 5.5(k). The calculations suggest that by using extensive green roofing on all roof surfaces throughout the study site, a reduction of 10% to the cost of sub-grade infrastructure could be achieved. If surface permeability approaching the levels found on the site under pre-development conditions, a 35.5% reduction in sub grade infrastructure could potentially be achieved.

Table 5.5 (k) - Site-wide Cost of Sewer Installation under Three Different Land Use Scenarios under Three Different Land Use Scenarios assuming a 20-year Storm of One Hour

Land Use Scenario	*Zone 1 pipe installation cost (per meter*	*Zone 2 pipe installation cost (per meter)*	*Zone 2 pipe installation cost (per meter)*	*Average installation cost (per-meter) for entire site*	*% savings in LDS installation costs*
Existing condition	$630.00	$540.00	$630.00	$600.00	—
Green-roofed condition	$540.00	$440.00	$630.00	$537.00	**10%**
Pre-development condition	$360.00	$360.00	$440.00	$387.00	**35.5%**

5.5.7 Projected per-annum cost savings to land drainage infrastructure construction within the City of Winnipeg under three land-use scenarios

Annual spending on land drainage infrastructure installation by both the City of Winnipeg and the private sector has been estimated at 2-million dollars and 5-million dollars respectively (personal communication with A. Nagy, June 19, 2001). By projecting the savings to land drainage infrastructure under two alternative land-use scenarios onto the annual budget for land drainage infrastructure, it is calculated that there would be a per-annum savings of $700,000 under the green roof scenario and a savings of $2,485,000 under the pre-development scenario.

Table 5.5 (I) - Projected Per-annum Installation Cost Savings to the City of Winnipeg under Three Different Land Use Scenarios assuming a 20-year Storm 1-hour in Duration

Land-use Scenario	*Average installation cost (per-meter) Civic LDS infrastructure*	*% savings in LDS installation costs*	*Projected annual savings in Civic LDS installation under each land-use scenario*	*Projected annual LDS infrastructure costs under each land-use scenerio*
Existing condition	$600.00	**0%**	**$0.00**	**$7,000,000**
Green-roofed condition	$537.00	**10%**	**$700,000**	**$6,300,000**
Pre-development condition	$387.00	**35.5%**	**$2,485,000**	**$4,515,000**

5.5.8 A cost comparison between green roofing, underground stormwater storage tanks and stormwater retention ponds

The framework used for these calculations were developed by Kuhn (1999). The cost of green roof installation were borrowed from Kuhn (1999) and verified for accuracy by a Soprema roofing representative (personal communication with G. Harrison, June 22, 2001). The City of Winnipeg Water and Waste Department provided the cost of underground stormwater storage tank installation, and stormwater retention pond installation (personal communication with A. Nagy, June 21, 2001).

The following calculations exclude yearly maintenance fees, and assume a conservative ten-year life cycle. These calculations assume the coefficient of runoff from green roofs to be 0.40 as derived by Durr (1995).

Assuming precipitation normals and current costs of construction within the City of Winnipeg, how would the cost per cubic foot of stormwater retention using underground stormwater storage tanks and stormwater retention ponds compare to that of green roofing?

Given the following, the cost to retain one cubic foot of water per year using green roofs can be calculated as:

1. The average annual precipitation in Winnipeg City is 21.25 inches

2. The cost to supply and install an extensive green roof is $15.33 sq/ft. or $1.53 sq/ft. per year (over a ten-year lifespan).

3. Assuming a coefficient of runoff of 0.40 and yearly precipitation of 21.25 inches, one square foot of green roofing would retain 1.0635 cubic feet of water throughout a one-year period in the City of Winnipeg.

4. Using extensive green roofing, the cost to retain one cubic foot of stormwater per year would therefore be $14.41.

5. Assuming a ten-year lifespan, the cost of stormwater retention would be $1.44 per cubic foot per year.

Given the following, the cost to retain one cubic foot of water per year using underground storage tanks can be calculated as such:

1. The approximate cost to build an underground stormwater storage tank is $30 per cubic foot of water retained (personal communication with A. Nagy, June 25, 2001).

2. Assuming a ten-year lifespan, the cost of stormwater retention would be is $3.00 per cubic foot per year.

Given the following, the cost to retain one cubic foot of water per year using stormwater retention ponds can be calculated as such:

1. At a cost of $1,000,000 a stormwater retention pond of typical depth and with a surface area of 5 acres would hold 1,765,700 cubic feet of water (personal communication with A. Nagy, June 25, 2001).

2. The cost to install a stormwater retention pond would therefore be $0.57 per cubic foot of water retained.

3. Assuming a ten-year lifespan, the cost of water retention using a stormwater retention pond would be $.057 per cubic foot per year.

Therefore, assuming a coefficient of runoff of 0.40, regional precipitation normals, and local costs of construction, extensive green roofs would cost approximately 52% less per cubic foot of stormwater retained when compared with underground storage basins. In contrast, extensive green roofs would cost approximately fifty times more per cubic foot of stormwater retention when compared to a typical stormwater retention pond.

5.9 Chapter summary

As calculated in Section 5.5 the widespread use of extensive green roofing on the study site would reduce stormwater runoff into Omand's Creek by approximately 17 - 21%. It is likely that this reduction would have many positive benefits to the health of Omand's Creek. These benefits include the reduction in the risk of localized flooding, filtration of pollutants commonly found in rainfall, partial mitigation of problems associated with erosion, streambank failure, sedimentation and the heating of stormwater runoff. By partially reducing the exigencies associated with stormwater runoff and pollution, extensive green roofing would benefit the riparian and aquatic habitat of Omand's Creek.

The use of green roofing at this study site may not necessarily decrease the risk of flooding in this area. Rather, green roofing could potentially increase the risk.

The downstream reach of Omand's Creek is susceptible to flooding induced by upstream sources of water. The City of Winnipeg Department of Water and Waste encourages landowners adjacent to this portion of the creek to drain their site runoff swiftly. This is to ensure that the downstream reach is free of water so that the later arrival of upstream flows can be managed (personal communication with A. Nagy, April 30, 2001). By absorbing water that could potentially be released into the system at a later time, green roofs could potentially conflict with the arrival of upstream flows. The delay time from the onset of rainfall until water begins to shed from a typical extensive green roof is approximately 30 minutes (Groseva, 1997). Timing is a critical issue that must be considered when designing green roof systems so that they do not conflict with upstream flows.

This study has indicated that the use of extensive green roofing would reduce the flow of stormwater runoff into the Tylehurst Combined Sewer System from 13-17%. However, a high proportion of the study site draining into the combined sewer system originates from rooftop surfaces. Because of this, the figures indicated above are very conservative estimates and could be as high as 25%. By keeping water out of the combined sewer system, the risks of combined sewer overflows would likely be significantly reduced through the use of green roofing in areas similar to this study site.

This analysis indicates that by reestablishing pre-development rates of runoff, a 43-50% percent reduction in runoff could be achieved. Given the compaction of the existing soils and owing to their high clay content, this would be a very difficult task to achieve (personal communication with A. Nagy, June 19, 2001).

Although the benefits of alternative means of stormwater retention (such as below grade storage tanks and stormwater retention ponds) must not be discounted, both have drawbacks. Aside from their prohibitive cost, below grade tanks do nothing to mimic the natural hydrologic cycle. Storage tanks simply hold water so that it can be released into the watershed or sewer system at a later point in time. By absorbing and transpiring water, and by producing oxygen in the process, green roofs mimic a small portion the natural hydrologic cycle. Although stormwater retention ponds create natural habitat and in many ways mimic the hydrologic cycle, these ponds require large areas of land usually in high demand and at high cost in the areas most in need of better stormwater management infrastructure. In suburban areas, where new developments are being planned and retention ponds can be integrated from the onset of the design development, stormwater retention ponds are a logical and cost effective means of controlling runoff. The same cannot be said for highly urbanized areas such as the study site.

Although the per-cubic foot cost of stormwater retention provided by green roofing is estimated to be fifty times that of a stormwater retention pond, stormwater retention ponds are not a feasible stormwater management solution outside of the suburban context. Below grade storage tanks and extensive green roofing systems appear to be better suited to urban sites. At half the cost of buried storage tanks per square foot of stormwater retention, and with their ancillary environmental benefits, green roofs may be the preferred urban best management practice with respect to urban stormwater management.

This chapter has demonstrated that extensive green roofing would reduce runoff from the study site by up to 17%. In doing so, a 10% savings to infrastructure costs could be achieved. The disproportionate relationship between the cost savings and the reduction in runoff suggests that although runoff would be reduced through the use of green roofs, the resulting reduction warrants only minor cost-savings in sub grade infrastructure. If a less conservative coefficient for runoff had been used, these savings would have been much greater. Tables 5.5(i) and 5.5(j) indicate that zone three within the study site would not have realized any savings to sub grade infrastructure had all of the roof surfaces within this zone utilized green roofing.

At a price of $15.30 per square foot, green roofs are double the price of a 4-ply ISO 1400 rated torch on asphalt roof with insulation. The roofing systems used on big-box retail outlets are single-ply torch on systems that are installed at a cost of $4.00 per square foot (personal communication with G. Harrison, June 22, 2001). Assuming a ten-year lifespan and not accounting for maintenance costs, the total cost of roofing all of the structures on the study site using the current system would be $187,420 per year. Assuming the same ten-year lifespan, if one accepts both the current development investment context of a ten-year time frame and the duration given for the life span of an asphalt roof, the total cost to roof the equivalent roof area using green roofs would be $716,881 dollars per year. This disparity in cost demonstrates the inherent difficulty involved in convincing developers to install green roofing on their facilities. Because of the cost of green roofing, its use within Canada appears to be limited to facilities owned by businesses, organizations and special interest groups who have integrated some form of environmental agenda within their respective organization.

Scholtz-Barth (2001) states that the advances in green roofing installation techniques made by European companies have reduced installation costs by 40%. If the same advances were made in North America, the cost of installing extensive green roofing would approach $9.00 s.f. In light of the additional benefits that are accrued through the use of green roofing (both environmental and economic), extensive green roofing may become an attractive roofing alternative to property developers and building tenants if similar reductions in installation costs were achieved.

Chapter Six –Research Summary and Recommendations

6.1 Overview

Although extensive green roofs have been used in Europe for over three decades, the North American roofing industry has only recently adopted this environmentally friendly roofing technique. While highlighting the role that green roofs could play in the management of stormwater, an investigation of the potential benefits of employing green roofing systems within the context of the Manitoba Capital Region was deemed to be a valuable project. Previous studies that have explored the use of extensive green roofing have done so on the scale of a single building. This advances these forward by looking at the potential benefits of green roofing at the scale of an entire site. It is hoped that other municipalities interested in furthering their knowledge of the potential benefits of green roof infrastructure will utilize this research document.

Chapter One of this thesis introduces the scope, research problem and methods used within the study. Chapter Two includes an extensive literature review. Chapter Three describes the development, dissemination and analysis of a survey distributed to the owners and managers of green roofed buildings located in the Province of Manitoba and in the State of Minnesota. Chapter Four reports on the selection and analysis of a Winnipeg study site with respect to the local and regional environmental influences on the site. The results of the site analysis are used in Chapter Five to calculate stormwater flowing off the study site under three different land-use scenarios, and to calculate the cost implications of utilizing extensive green roofing within the site and within the City of Winnipeg.

Chapter Six of this research restates the research problem as defined in Chapter One and reviews the research methods used. Conclusions with respect to the research questions posed by this study are drawn. A series of recommendations drawn from the literature review, the participant survey, and the site analysis/stormwater calculations and economic valuations are outlined in Sections 6.5, 6.6 and 6.7. Conclusions and final recommendations are discussed with an emphasis placed on directions for further study and suggested policy initiatives.

6.2 Research Problem

The research problems explored by this document are as follows:

1. Emphasizing cold climate performance, are there any local examples or cases within close proximity to the Manitoba Capital Region that could indicate the potential merits and/or shortcomings of living roof systems within the context of this region?

2. To what degree might extensive living roofs reduce stormwater runoff, decrease sub-grade infrastructure costs, and benefit the ecological health of a designated study site located within the City of Winnipeg?

6.3 Methods summary

In order to explore the research problems, this study utilized several different methods of inquiry. A brief summary of these methods is given below. Chapter One of provides a more detailed summary of the methods used. Chapters Three and Five present further detail on the methods used within those chapters.

The introductory section of this thesis reviewed literature from scholarly journals, roofing industry publications, books and technical documents. Two periodicals of particular importance to this study were translated from German to English for the purposes of this literature review (see Drefahl 1998, and Durr 1995). Additional data were gathered via telephone conversations, e-mail, faxes and Internet sources. Professionals from architecture and urban planning organizations, non-profit coalitions, the City of Winnipeg, Environment Canada, the National Research Council of Canada, the International Institute for Sustainable Development, the Swedish Council for Building Research, and a variety of other organizations have provided information used within this study.

Following the literature review, Chapter Three involved a participant questionnaire. Survey data were collected from individuals who are directly involved in the maintenance and upkeep of eight intensive green roofed buildings that were identified in the Province of Manitoba and the State of Minnesota. This survey analyzed the effectiveness of these green roofs and assessed (among other things) their cold weather performance, their ability to retain stormwater, their relationship to the natural environment, and the public reaction to these projects. This questionnaire was conducted upon approval from the University of Manitoba Joint-Faculty Research Ethics Board (see Appendix A).

Chapter Four of this study analyzes a site that is located adjacent to the urban downstream reach of Omand's Creek in the City of Winnipeg, Manitoba. The site is used as the basis for the stormwater calculations performed in the following chapter. The criteria for the selection of this site are outlined in Chapter Four section 4.10.

The data derived from Chapter Four are used in Chapter Five to calculate the runoff generated from this site under five-year and twenty-year storm conditions. Assuming the widespread use of extensive green roofing, a simulation of the runoff generated from the study site under the same storm intensities was conducted. The results of each scenario were then compared. The potential savings to the City of Winnipeg and to private developers assuming the widespread use of green roofing were then projected. The cost per cubic foot of water retention using green roofing, below-grade storage tanks, and stormwater retention ponds was calculated and compared. Conclusions regarding the potential economic cost and probable ecological benefits of green roofs as an alternative means of stormwater management were then drawn.

6.4 Study results

The research question posed within this document is twofold. The first question is an inquiry into the successful application of extensive green roofs constructed within close proximity to the Manitoba Capital Region with an emphasis on cold climate performance. All building owners surveyed within this study affirmed that the green roofs on their buildings were well suited to cold northern climates. Most respondents noted that their green roofs had preformed well, minor problems were frequently reported. Only one of the building owners surveyed noted that major repairs were required on the subject roof. The findings in Chapter Three indicate that extensive green roofing systems have been successfully utilized within cold northern climates. The owners and managers have been very pleased with the success of these systems and have indicated that these systems are attractive, ecologically friendly and often serve an important public educational purpose. Although the majority of the systems surveyed were small in scale, their success indicates their viability on a larger scale.

The second question posed within this research asks to what degree might extensive living roofs reduce stormwater runoff, decrease sub-grade infrastructure costs, and benefit the ecological health of a designated study site located within the City of Winnipeg. The results from Chapter Five indicate that the use of extensive green roofing on a local study site would reduce site runoff from between 16-17%. The use of green roofs as an alternative means of stormwater retention could reduce the cost of sub-grade infrastructure by 10%. Although the costs of green roofs per cubic foot of stormwater retention per year is significantly greater than that of utilizing stormwater retention ponds, green roofs can provide stormwater retention at up to half the cost of using underground stormwater storage tanks. The use of extensive green roofing on the study site used in this research would reduce the amount of runoff flowing into an adjacent creek from 17-21% and into the combined sewer from 13-17%. Although the ecological benefits associated with reducing stormwater runoff into these two systems are not directly studied, the potential benefits with respect to pollution reduction, streambank erosion and sedimentation are stated in Section 5.9.

6.5 Recommendations from Chapter Two - Literature review

Section 2.1 of the literature review provides the reader with a summary of the divergent themes regarding the role of the ecology in design. From the importance of the science of ecology as advocated by McHarg, to the cultural harvest that ecology brings to design as noted by Corner; the myriad of disparate themes and opinions is evidence of the importance of such dialogue. As the professional associations of architecture and engineering have adopted green manifestos so too should the professional associations related to landscape architecture. The Canadian Society of Landscape Architects has recently tabled a sustainability declaration for the profession. If adopted this document will be instrumental in furthering the role that the profession of landscape architecture will play within the realm of ecological design.

Advancing the notion of "biomimicry", Hawken et al. (1999) and Todd (1984) advocate the redesign of industrial systems. In mimicking the natural flows found in nature, one producer's waste becomes another producer's input. Not only should industrial processes be the targets of reorganization according to the principles advanced by Todd (1984) and Hawken et al. (1999), so too should civic infrastructure. Stormwater quickly shed into rivers and streams through the costly underground maze of catch basins and conduits results pollution, sedimentation and erosion. Stormwater should no longer be treated as a burdensome byproduct of the urban condition. It should be used as an input in support of green infrastructure.

As indicated by Franklin (1999), design solutions need not adhere fanatically in their attempt to reestablish natural conditions. The inherent value in maintaining natural process must be recognized. Whether found in the form of constructed wetlands, green roofing or vertical gardens, natural process can and should be replicated as much as possible through integration into site infrastructure. By involving professionals from all realms of design as well as from the natural sciences, the foundation for new and integrative systems can be established.

There is a need for the designer to reconsider the context within which he or she is designing. This begs the question of how the rooftops of the Manitoba should be designed to reflect the nature and context of this place. This is a question that involves further critical inquiry. Nevertheless, it is hoped that the examples given herein will inspire designers to place nature and its inherent efficiencies above the axiom of economies of scale. In so doing, design will better reflect local context, culture and ecology.

The lack of regionally specific literature and data presented in Chapter Two indicates the need for research into the design of an extensive green roofing system best suited to the climatic and geographic context of the Manitoba Capital Region. Plant selections, substrates, the opportunity to utilize recycled materials and specific fire precautions that need to be taken are only a few of the many topics require study at the local level. A pilot project that would allow for the collection of site-specific data would be very valuable to the future of the green roof industry in the Province of Manitoba. The University of Manitoba faculty of Architecture in conjunction with the department of Botany would make a natural partnership in conducting a local green roof pilot project.

My review of literature pertaining to the ecology of the rooftop found in Section 2.4 suggests that we must change our thinking with respect to roofing in a number of ways. Not only should we begin to consider rooftop surfaces as valuable and ecologically productive space, but we should also reconsider how we monitor these surfaces. Rather than infrequent inspections with stopgap repairs being done when systems begin to fail, the use of extensive green roofs will likely necessitate more frequent inspections. By taking an interest in the health of these surfaces, their life span will be greatly increased. The increased capital costs and the costs associated with monitoring these roofs should be recouped over the long term, as maintenance costs would likely be lower.

The literature points out a variety of green roof demonstration projects that are currently underway in North America. The continued monitoring of these projects would be beneficial to the public promotion of green roofs within Manitoba. By demonstrating the success of green roofs located in other municipalities, members of the public will become less skeptical of this roofing technique.

In addition to demonstration projects, my review of research being undertaken by the National Research Council of Canada indicates that the data generated by the NRC could be used to assist planners and designers working on green roofing projects within the City of Winnipeg. The current NRC studies explore the potential energy efficiency gains and environmental benefits of green roofing. The results are expected to help promote extensive green roofing within the Winnipeg context and stimulate strategic "roof greening partnerships" between building owners and utility companies in an effort to achieve higher levels of energy efficiency.

European literature has indicated that the standards set within the roofing industry were based on tests that were conducted in controlled laboratory conditions. External conditions are much more harsh that that of a laboratory, because of this, European green-roofing standards were not set high enough (Drefahl, 1998). This suggests that wherever possible, studies should be conducted under actual conditions and there should be an emphasis placed on identifying studies that have been conducted on green roofs outside of the laboratory.

As Drefahl (1998) suggests, the European green roof industry is at a critical juncture in its development. Roofs are now exceeding thirty years of age. Steps should be taken to uncover the failure rate among these roofs. North Americans must heed the cautions regarding the inexpensive single-layer green roofing systems as acknowledged by Drefahl (1998) and by Krupka (1995). The North American roofing industry is highly competitive. The use of sub-standard green roofing materials and systems in any effort to drive roof prices down would prove to be very harmful. Suggestions made by Europeans with respect to standards must be given due consideration.

I have made reference to European research throughout this study. When compared to North America, the problems associated with urban growth have taken on a very different sense of urgency in Europe. Ecologically based design solutions are readily used and accepted throughout Europe. This does not mean that the situation is any less urgent in North America. The receptiveness of the North American public toward the notion of ecological design is a topic that must be explored further.

Studies looking at maintenance costs, plant mixes, substrate mixtures membrane durability and the use of recycled materials in green roof design were discussed throughout the literature (see Sections 2.7 to 2.9). The majority of the studies were from European sources. This further highlights the need for North American data.

Whalley (1978) suggested that the extensive roof greening of flat roofed industrial and commercial buildings would enable the development of afterthought landscape schemes of reasonable meaning and expressiveness. The benefits of creating afterthought landscapes using extensive green roofing are many. However, by gaining a better understanding of green roofing techniques, designers will become less hesitant to look at extensive roof greening as an afterthought. The purposeful design of extensive roof greening onto new projects will enable greater thought with respect to the roofscape of our city. The fundamental sense of shelter that rooftops provide people with, as implied by Alexendar (1977), could be reestablished.

6.6 Recommendations from Chapter Three - Participant surveys

The green roof on the Ducks Unlimited Oak Hammock Marsh Conservation Centre (Case Study Two) is the oldest of the roofs studied and the only roof to have had a faulty waterproofing membrane (the apparent result of improper materials and damage during installation). This indicates that standards for both membrane quality and installation procedures should be developed. EPDM may not be the best choice of membranes for large-scale projects as it is highly susceptible to puncture. The two largest buildings in this study have chosen to utilize liquid torch on membranes.

Liquid membranes are generally considered to give superior waterproofing protection and are easier to maintain (Valasquez, 2001). Drefahl (1998) notes that when a floating membrane is used, a temporary cover should be put down prior to giving trades people access to the roof. A roofing industry representative noted that EPDM membranes often incorporate recycled materials (personal conversation with G. Harrison, June 18, 2001). Although commendable, recycled products should be considered for use only after adequate testing.

The legal costs incurred by this facility in settling issues related to liability due to roof failure indicate a lack of appropriate insurance policies available to those who utilize extensive green roofing. If policy alternatives and insurance schemes designed to protect those who employ green roofing cannot be developed, the risks associated with green roofing may dissuade building owners from using it. Better materials testing, standards, installation procedures and subsequent performance guarantees would prove valuable to the industry.

The high survival rate of the plants on the roofs surveyed is likely a result of widespread use of native vegetation. As a suggestion for further study, it would be valuable to profile the plant types used on these roofs so that a comprehensive list of plants suitable for use on green roofs in cold climates could be established.

Two structures out of the nine examined used traditional techniques in construction. Constructed using locally available materials, these roofs have performed well. In considering the performance and viability of green roofing in cool northern climates, the importance of vernacular knowledge must not be overlooked.

Such knowledge is valuable to private citizens who are interested in green roofing as it can be readily utilized by individual homeowners on a residential scale.

The common belief that green roofs create a fire hazard is a concern that must be addressed. The designers of these systems must do a better job in informing the public of the steps that are taken in the design and construction of green roofs to ensure adequate fire protection. A common protocol for fire protection must be established. Sub-section 2.7.7 outlines current standards used in Europe. The North American green roof industry should follow suit in establishing similar standards and pursue a fire rating process for extensive green roofing.

The receptiveness of planning authorities to these roofs ranged from being "warmly receptive" to "enthusiastic". It is essential that information with respect to extensive roof greening practices be made available to planning authorities so that the concerns of local with respect to these systems can be managed in a timely fashion. Case Study Nine highlighted a situation where planning authorities were unable to approve or disapprove of the participant's proposal to construct a green roof. Because such a proposal had never been made, and planning authorities were unaware of green roofing techniques, their initial response was to resist the proposal. The lack of responsiveness to green-roofing techniques must be overcome by planning authorities. Efforts must be made within all levels of government to educate policy makers about green roofs so that appropriate policy and approval mechanisms can be developed.

In constructing extensive green roofs the cost of transporting soil to the roof surface has proven to be expensive (see Case Study Two and Case Study Four). It may be necessary to determine or develop an efficient and cost effective means of conveying the growing medium to the roof surface. Because extensive green roofing is new to this region, the development of efficient installation practices will be fundamental to the future development of this roofing practice. European methods of production, transportation and installation should be researched in greater detail. The Swedish firm Veg Tech has developed a machine that distributes plant cuttings into mixed soil. The cuttings and soil are transported onto the roof by a large diameter hose, this has proven to be 1/3 less expensive than the propagation of the $1m^2$ vegetation mats (personal communication with David Van Vliet, July 8, 2001).

The reduction in green-roof installation costs that have occurred over time as the European industry has advanced must be explored further. It would be useful to understand the cost efficiencies that could be achieved in the North American marketplace. Demonstrating this would enhance the viability of the green roof industry within North America.

Given the relatively young age of the roofs studied, their true resilience to cold climate cannot be known for many years. Efforts should be taken by researchers interested in green roofing to monitor the roofs studied within this document over the long term so that future problems can be documented. The wide variety of soil mixtures and depths suggests that there is no prescribed technique for installing green roofing that is suited to the cool northern climate. Because these roofs are the "pioneer prototypes" of future North American cold climate green roofs, observations with respect to roof maintenance, plant survival, substrate condition, drainage and system wear that could inform future green roof design should be compiled. A nongovernmental organization such as the Green Roofs for Healthy Cities Coalition is an ideal group to spearhead such an effort. By developing a common research database that is contributed to by member organizations throughout the country, information pertaining to green roof performance from across the country could be collected. An index of best practices in design specific to regional conditions could be compiled and made available to member organizations, roofing professionals, the construction industry, professional associations, and the government. The German Roof Gardening Association (Deutscher Dachgartner-Verband) and the The Landscaping and Landscape Development and Research Society of Germany (Forschungsgesellschaft Landschaftsba Landschaftsentwicklung) are excellent examples of European organizations committed to providing industry professionals with information regarding recent industry developments. The North American industry should form similar organizations so that green roof information can be freely exchanged.

None of the informants had collected data regarding runoff from their respective green roofs. It would be beneficial to the green roof industry if the academic community worked with the owners and managers of green roofed buildings in an effort to compile such data. Funds that would otherwise go into the construction of study prototypes could then be redirected toward additional research. This information would be very beneficial to future efforts related to the implementation of a long-term municipal green roof strategy within the Manitoba capital.

The majority of the facilities studied are located in rural locations. It would appear that the desire to maintain the unspoiled landscape of exurban locations is quite strong among the survey participants. Further studies should be completed in order to understand if there exists a resistance with respect to the use of green roofing within urban areas. A recently unpublished graduate thesis from Iowa State University entitled Analyzing the green roof: A critical dialogue (Peterson, 2001) addresses the lack of critical and theoretical analysis with respect to the green roofs. The author notes that it is essential that landscape architects "explore the cultural issues of green roof design in order to accept and promote this sustainable design practice" (p.1). It would be valuable for organizations interested in promoting the use of extensive green roofing to continue to research the cultural precepts and barriers to sustainable design. By understanding the common uncertainties regarding green roofing and the integration of ecology and design, steps toward overcoming such entrenched attitudinal barriers can be made.

Despite the lack of regionally specific research and regardless of the process of trial and error that has been employed with many of the roofs studied, the owners and managers of these facilities remain pleased with the performance of their respective roofs. By networking owners and managers of pre-existing green roofed buildings and green-roofing professionals, valuable knowledge regarding best practices in design, product and plant specification, installation, and maintenance could be established.

The reported survey results indicate the success of green roofs within southern Manitoba and Minnesota. These success stories are critical to the promotion of green roofs within the Manitoba Capital Region. Efforts by all levels of government should be made to continue to collect and compile locally available data and case studies.

6.7 Recommendations from Chapter Five - Stormwater valuations

In order to fully understand the benefits to urban watershed health that could accrue through better stormwater management practices, the modeling of entire watersheds is essential. Looking at the response of discrete areas to limited storm events is not a sufficiently accurate means to understand or derive accurate conclusions. Watersheds are inherently complex systems, dynamic models that better account for this complexity must be developed. Although the results derived within Chapter Five safely contend that the use of extensive green roofing would benefit the Omand's Creek watershed, more accurate models need to be developed.

There is a need for more and better data with respect to green roofs in the context of the Manitoba Capital Region. A coefficient for runoff, which more accurately reflects this region, should be determined. With several Winnipeg building owners (such as Mountain Equipment Co-op, the Red River Community College Downtown Campus and the Birks Building) expressing a desire to utilize extensive green roofing, researchers interested in green roofing should make every effort to gather data from these roofs before, during and after their construction. If a coefficient for runoff specific to the Manitoba capital Region can be determined, and if this coefficient of runoff can be shown to be between 15 – 25%, the resulting savings to below-grade stormwater infrastructure would be much greater than those reported herein and based on the coefficient employed in the Omand's Creek analysis.

Chapter Five asserts that extensive green roofing could prove to be a valuable best management practice in reducing urban stormwater runoff. By comparing runoff from the study site under the green roofed condition with pre-development rates of runoff, the need to reevaluate the way we treat all urban surfaces must be considered. Rooftops have immense untapped potential as sources of habitat and stormwater storage. Used in conjunction with permeable paving surfaces, ponds, vertical gardens, constructed wetlands and street trees, the ecological and economic return could be significant. Studies that consider green roofs in conjunction with a variety of different stormwater management and permeable surfacing techniques should be undertaken.

Because of Winnipeg's aging infrastructure and high proportion of combined sewers as indicated in Section 4.3, a variety of different best management practices with respect to urban stormwater management need to be developed. Although not a panacea for our urban stormwater management problems, the unique adaptability of green roof systems, their cost effectiveness, the savings that they could garner, and the sheer expanse of unused flat roofing in this city; extensive green roofing deserves to be placed at the forefront of future studies with respect to alternative stormwater management practices.

The up-front cost of green roof supply and installation is perceived as prohibitively expensive, especially among developers who stress the need to minimize initial capital investment costs. In terms of initial investment costs, green roofing cannot compete with standard roofing systems. In order to make green roofing attractive to developers, several things should be done. Firstly, if installed properly green roofing in Europe under similar regional environmental conditions has been shown to more than double the life span of the roofing system (Drefahl, 1998). The long-term durability of green roofing must be must be researched within the

North American context. By completing such research, the long-term reductions in capital cost could prove attractive to interested developers. Secondly, this study has not taken into account the maintenance costs of standard versus green roofing. European literature suggests that that the long-term maintenance costs of green roofing are lower than those associated with standard roofing (Grozeva, 1998). The potential savings in long term-capital investment costs attributable to the lower maintenance costs of green roofing within North American context should be further studied. This study demonstrates the potential cost savings to land drainage infrastructure that developers could benefit from if they were to utilize extensive green roofing. Nevertheless, if developers are to be convinced of the benefits of extensive green roofing, credible data with respect to the economic savings achievable through the longer life span that extensive green roofs are purported to have must be gathered and disseminated by agencies such as the Green Roofs for Healthy Cities Coalition.

It is imperative that private developers, planning authorities, and all government departments with jurisdiction over the environment and water resources begin to take notice of the potential role that green roofing could play as an alternative means of stormwater management. The City of Winnipeg has studied the viability of using stormwater detention tanks to address its antiquated and overburdened land drainage infrastructure and has subsequently determined that the cost of installation of these systems prohibits their use (personal communication with A. Nagy, June 22, 2001). Green roofs are less than half the cost of underground storage tanks per cubic foot of water retained. With ample roof space to accommodate green roofs within the City of Winnipeg, further studies should be undertaken in order to firmly establish regional design criteria and the viability of green roofing systems within the Manitoba Capital Region.

As discussed in Chapter Four, the potential for using green roofs as a source control means of stormwater management in the City of Winnipeg must not be overlooked. The calculations completed in Chapter Five corroborate the findings of Cigana (2000) in Section 4.3. Namely, I found in Chapter Five found that green roofs (as source-control method of stormwater management) were determined to be a more cost effective and flexible solution when compared to below grade storage tanks and stormwater retention ponds. Further detailed studies should be completed so that more accurate cost comparisons can be made. The calculations completed within Chapter Five should be considered as preliminary. Nevertheless, green roof infrastructure should no longer be overlooked as a part of a comprehensive stormwater management strategy for the City of Winnipeg.

In addition to their economic benefits, their ability extend the life span of roof surfaces, and their benefits to stormwater management, there are ethical considerations that must also be addressed. Green roofs would greatly benefit the urban ecology of this city by reducing the urban heat island effect, filtering air, and helping to reduce greenhouse gasses. Beyond their economic value, there is an ethical imperative to creating places that are responsive to the needs of our environment. Hawken et al. (1999), point toward a future where the reinvestment in natural capital buttresses and expands the life sustaining influences of the earth's ecosystems. Beyond their utility as stormwater retention surfaces, green roofs mimic a small but vital portion of the natural hydrological process that those that design and invest in below-grade land drainage systems simply ignore. There is clearly a need to advance the moral imperative and the long-term economic efficiencies associated with designing urban systems to mimic nature rather than merely placing nature underground.

6.8 Extensive roof greening in the Manitoba capital region - Suggestions for further research

Used within the Manitoba Capital Region, the potential risks and benefits that are associated with the widespread use of extensive green roofing are numerous. In order to fully understand these risks and benefits further studies must be completed. Owing to the regional specificity in design demanded by green roofing systems, there is a clear limitation placed on the amount of information the can be adopted from both out-of-province and foreign sources. Ultimately, regionally specific research and demonstration pilot projects must be completed.

A list of plant species considered suitable for use on extensive green roofing within the Manitoba Capital Region must be determined (see Appendix D). Plants that are able to grow in thin soils, are drought resistant and can withstand extreme fluctuations in temperature and precipitation are thought to be ideal candidates. The danger posed by invasive weedy species with aggressive rooting systems that could potentially damage waterproofing membranes must also be determined. Kurzman, Kalthoff and Fischer (1981) determined that thistle poses a risk to green roof membranes. Because of the prevalence of invasive thistle in Manitoba, this caution must not be overlooked.

Kolb and Schwartz (1986) note that frost has a tendency to loosen, to heave and eventually cause cracking in green roof substrates. This exposes plant roots and leads to increased winterkill. These authors note that if the appropriate clay content is used in the substrate, the effects of frost heave can be minimized. A regionally specific substrate suited to the periods of extreme cold and able to withstand frost heave must be developed.

Green roofs within the Winnipeg region must be further studied with an emphasis placed on precipitation and temperature. To accurately do so, a variety of prototypes suited to local conditions should be developed. Among other things, each prototype surface should be monitored for runoff, survivability of the plants used, drought tolerance, cold climate performance, and maintenance requirements.

The integration of appropriate fire precautions must be studied if green roofs are to be considered an effective roofing alternative to be used within the prairie region. Literature suggests that fire precautions require due consideration yet are too often ignored (leading to an obvious public relations problem for advocates of extensive green roofing). Because prairie ecosystems experience frequent periods of drought, and because fire is a naturally occurring regenerative process common to the prairies, fire precautions must not be overlooked. The building codes with respect to fire protection currently used within Europe are valuable information (see sub-section 2.7.7). Nevertheless, this must be explored from a regional perspective.

Whalley (1978) found that excessive heat loss from buildings led to a condition in which plant roots would thaw out during the winter and refreeze when temperatures dropped lower. This condition brought roof plants out of their dormant stage in the winter and lead to excessive winterkill and eventual failure of the green roof. A similar problem was uncovered in Case Study Nine. The thermal efficiency of the local building stock must be assessed for its suitability to extensive roof greening.

Owing to the regional specificity of green roof plants and the potential for recycled components such as root barriers, drainage mats and composted organic waste, the potential for the development of locally based market for green roofing products and services exists. Further studies regarding the potential local economic spin-offs resulting from the development of this industry would be beneficial.

Likewise, it is suggested by Scholtz-Barth (2001) that green roofs that are dry have a greater thermal efficiency than wet substrates. Scholtz-Barth notes that heat loss due to wind can be reduced by up to 50% by adding a layer of green roofing. The windy and dry conditions common to the prairies suggest that the use of extensive green roofing in this region would be highly beneficial to the thermal efficiency of the existing building stock. Further research should be conducted so that the potential energy efficiency benefits attributable to green roofs used within the local context can be validated.

Although this final chapter has touted the benefits of regionally specific research, I recommend that a broad based research protocol be developed so that all green roofs, regardless of where they are located, could be evaluated according to common criteria and themes. I hope that parts of this study will be used as a source of information by other municipalities and organizations interested in studying the viability of using extensive green roofing within their communities. However, more must be done to facilitate consistency in the methods of evaluating the potential gains that communities stand to make by adopting the used of extensive green roofs.

A brief summary of the major areas that require further research within the regional context of the Manitoba Capital are as follows:

- The development of prototype roof suited to Manitoba (substrate type, plant mixes etc.)
- Monitor runoff, cold climate performance, thermal efficiency and maintenance / weeding requirements of the proposed prototype
- Study potential economic spin-offs of the green roof industry
- Explore the use of green roofs in managing wet weather flows in concert with other methods of stormwater management (determine best practices)
- Study the existing urban building stock and assess its potential for the retrofit of extensive green roofs

6.9 Extensive roof greening in the Manitoba Capital Region - Suggested policy initiatives

Other North American municipalities have adopted several policy initiatives and green roofing demonstration projects as a means by which to further the accepted use of extensive green roofing. The City of Toronto and the City of Chicago have made progress in educating the public about the urgency of rethinking urban infrastructure. The City of Toronto has integrated the use of green roofing into the wider context of an overall strategy for stormwater mitigation. The City of Winnipeg and the Province of Manitoba would benefit greatly from following these examples. Rooftop greening demonstration projects should be completed on the rooftops of City of Winnipeg owned buildings that have good public access. Green roof education and awareness programs should become a priority of the City of Winnipeg. The Center for Indigenous Environmental Resources (CIER) has received a grant from the Canadian Federation of Municipalities to determine the costs and benefits of developing and implementing green roof infrastructure as part of a comprehensive stormwater management strategy for the city of Winnipeg. The CIER study will be a useful tool in introducing City administrators and policy makers to a new model of green infrastructure and public works. In addition, green procurement policies for publicly owned buildings should include the use of extensive roof greening wherever possible. For example, the Federal Department of Public Works and Government Services, the Provincial Department of Government Services Procurement and Property Management Offices, and the City of Winnipeg Public Works Department should consider green roofing as a part of an overall green procurement policy. Tenders and government contracts could reduce the consequences of environmentally damaging construction practices by specifying materials such as extensive green roofing.

City of Winnipeg planning and property development policies should be used as a means to make the use of extensive green roofing attractive private developers. To attract private developers toward the implementation of green building strategies, a reduced property tax assessment could be given based on the amount of green roofing utilized. In Portland Oregon, a floor area ratio bonus is given to private developers who utilize green roofing. Where green roofs make up 10-29% of the building's footprint, each square foot of green roof earns the building owner one square foot of additional floor area. Where the total are of the green roof is between 30-59% of the building footprint, each square foot of green roof earns two square feet of additional floor area. Where the total area of the green roof is 60% or more of the building footprint, each additional square foot of green roof earns three additional square feet of floor area (GRIM, 2001).

The floor area subsidy as used in Portland is appropriate to locations that experience a high demand for commercial and industrial properties. In Winnipeg, the demand for commercial and industrial space is moderate. A floor area ratio bonus might work under limited circumstances. A more viable policy approach within the Winnipeg context would be to offer a subsidy to the sewer rate surcharge that is placed on commercial and industrial building owners who choose to utilize green roofing. This type of policy might be attractive to owner-operated structures. However, it would not be attractive to developers who lease properties.

In the state of Illinois, urban runoff is proving to be a problematic source of soil erosion. Thus, the Office of Agriculture and the Office of Soil and Water Conservation offer a reduced tax assessment to property owners of up to 5/6 of the land value for developers who use vegetated buffers to mitigate soil loss due to erosion (Shcholtz-Barth, 2001). The City of Winnipeg should consider a policy of tax assessment reassessment based on the percentage and type permeable surfacing used by developers. Because this policy would benefit the provincial responsibility for pollution control and the shared federal/provincial responsibilities for health, these levels of government should contribute toward a more progressive taxation scheme with respect to relationship between urban development and water resources.

Peck et al. (1999) observe that the green roofing industry in Germany has grown as a result of local by-laws and regulations. As a result of legislation passed in 1989 as well as financial and building density allowances incentives, the green roof industry in Germany has grown over the past decade. Because the industry remains in its infancy in North America, strict by-laws are not feasible. However, as the industry continues to develop within North America, a combination of by-laws and progressive taxation initiatives with respect to surface treatments should be developed and implemented.

Peck et al. (1999, p.45) outline five reasons for the lack of government support within Canada and North America with respect to green roofs. These are as follows.

1. Lack of easily accessible information regarding the, the social environmental and economic benefits.

2. The benefits are long-term while the capital costs are up-front, which is a strong disincentive to those who would otherwise invest in green roofs in the existing capital finance environment.

3. Many of the economic benefits are not necessarily accrued by the initial developers or investors, or are public in their nature.

4. There is little information regarding local green roof success stories.

5. Many social benefits will result from widespread application, partly in cities, but these are not captured in the current marketplace (highlighting the need for government market stimulus).

Strategic partnerships between energy suppliers and building owners would be a beneficial initiative. Toronto Energy Services is presently working with Toronto area schools to fund the installation of a green roof as a part of its energy efficiency upgrades. These roofs are also used for education purposes. Strategic partnerships between local energy suppliers and building owners should be coordinated at a local level.

Drefahl (1998) notes that it was only recently that the German green roofing industry began to develop industry standards and certify professionals with the credentials to evaluate and approve proposed green roof projects. Drefahl recommends that by creating a professional designation, and by having the roof inspected at various stages of its installation, guarantees with respect to roof performance can be made. From this, suitable insurance schemes can be developed so that the costly risks associated with green roof failure can be limited. Policies should be put in place so that the industry develops according to pre-determined standards. The European experience has taught us that the sooner this is achieved the more viable and effective the industry will become.

The U.S. Green Building Council's Leadership in Energy and Environmental Design Program (LEED) has listed five different ways in which green roofing can be utilized in order to qualify for LEED certification (LEED, 2000). The inclusion of green roofing into the LEED certification criteria is a significant step which underscores the validity of these systems.

A brief summary of suggested policy initiatives that could be implemented within the regional context of the Manitoba Capital are as follows:

- Government sponsored demonstration projects
- Floor-area subsidy for green roofed buildings (density allowance incentives are used in Oregon and Germany)
- Progressive property taxation policy to attract private developers (based on permeability of surfacing materials)
- Subsidize sewer rate surcharge currently placed on industrial and commercial businesses
- The development of industry standards to offset the risks associated with uncertainty of the systems
- Make extensive green roofing a part of government green procurement policies

6.10 Extensive green roofing in the Manitoba Capital Region - The future of the urban epidermis

Van der Ryn and Cowan (1996) contend that we are now entering the second phase of ecological design. That is, we are moving away from small-scale prototypes and toward larger commercial and industrial scale ecological design solutions. The present research corroborates this notion as the participants surveyed in Chapter Three indicate their overall satisfaction with their green roofs at the small prototypical scale, while the larger scale green roofs studied encountered difficulties that were a result of moving beyond the small-scale prototype. Nevertheless, the key informants representing the larger scale facilities were optimistic about the future of extensive green roofing within this region.

Chapter Three of this research demonstrated the much-needed green roof success stories at both regional and local levels. The ecological, environmental and economic benefits of extensive green roofing are significant enough to warrant further study. The results of this research are intended to contribute to an existing body of knowledge and will serve as a valuable resource to policy makers, designers, developers, builders and members of the public alike.

Research on green roofs within the North American context is still in its infancy. I expect that further studies further studies will lead to better and more efficient green roof design solutions and the industry will gain acceptance by developers and the by the general public. By continuing to learn from the European experience and by paying greater attention to local conditions, the barriers to the widespread use of extensive rooftop verdure will be overcome. In time, as our image of the city becomes more receptive to the needs of the environment, our cities will become active biological entities that are inviting to nature and responsive to natural process.

REFERERNCES

Alexander, C. (1977). A Pattern Language. New York: Oxford University Press.

Andrews, D. (1999). Omand's Creek Riffle Site Development Plan. Technical Report Prepared for the Friends of Omand's Creek by Dennis Andrews Consulting (March, 1999)

Archaeologists dig up some of Nebuchadnezzar's legacy. (December 3, 1998). Associated Press. [On-line] Available: http://www.crystalinks.com/ziggurat.html (January 26, 2001).

Blair, T. (1996). Climate. In Welsted, J.E., Everitt, J. Stadel, C. (Eds.). The Geography of Manitoba: Its land and people. Winnipeg: University of Manitoba Press.

Bovin, M. –A., Challis, G. (1998). Technical: Greening the Landscape. Canadian Architect, 37-37.

Cayley, D. (1991). The Age of Ecology. Toronto: James Lorimer and Company

Canadian Climate Normals 1961-1990 (1998). Environment Canada. [On-line] Available: http://wwwcmc.gc.ca/ climate/normals/MANW004.HTM (April 5, 2001).

CH2M Gore & Storie. (1996). CSO Management Study Phase Two Report. (Prepared for the City of Winnipeg Water and Waste Department). Winnipeg, Mb.

Cigna, J.F. (2000). Working Out Wet Weather Issues. Pollution Engineer. (32)6, 50-52

City's Sewers Second Worst in Canada. (1994, December 4). The Winnipeg Free Press.

City of Toronto. (1999). Demonstration of Non-structural Stormwater Management Practices-North Bloor West Village Study Area 1 (Draft Tech. Rep.), In Aquafor Beech Ltd., Laura Group, Schollen and Company, Centre for Watershed Protection, M. Kuhn, Geomatics International Inc. (Eds.), Toronto: City of Toronto Publication.

City of Winnipeg. (2001) Towards a Sustainable Winnipeg- An Environmental Agenda 2001. [On-line] Available: http://www.city.winnipeg.mb.ca/interhom/mayors/ green_agenda.htm (January 22, 2001)

City of Winnipeg. (2001). Combined Sewers and River Quality. [On-line] Available: http://www.city.wimnnipeg.mb.ca/interhom/services/browater/sewers.htm (February 27, 2001).

City of Winnipeg, Planning, Property and Development Department Planning and Land Use Division Waterways Section. (2000). Riverbank Stability Characterization Study for City Owned Riverbanks.

Collicut, D.(1994). The Wildlife of Omand's Creek. Nature North. [On-line] Available: http://www.naturenorth.com/winter/omandck/Fomck.html (May 8, 2001).

Corner, J. (1997). Ecology and Landscape as Agents of Creativity. In G.F. Thompson, & F.R. Steiner (Eds.). Ecological Design and Planning. New York: John Wiley and Sons.

Curtis, W.J.R. (1986). Le Corbusier: Ideas and Forms. Oxford : Paidon Press

Del Barrio, E.P. (1998). Analysis of the green roofs cooling potential in buildings. Energy and Buildings, 27, 179-193.

Donnelly, M. (1992). Architecture in the Scandanavian Countries. Cambridge, MA: MIT Press.

Drefahl, J. (1998). "Dachbegrunung Zeitbombe oder wirtschaftlicher Langzeit-Dichtungsschuts". "Green roofs: time bomb or economic long-term waterproofing protection". Deutsche Bauzeitschrift, 46,1, 89-94.

Durr, A. (1995). Dachbegrunung: Ein Okologischer Ausgleich. Green Roofs: An Ecological Balance. Bauverlang, GmbH. Weisbaden and Berlin: Germany.

Eckbo, G., Sullivan, C., Hood, W., & Lawson, L. (1998). People in a Landscape. New Jersey: Prentice Hall Inc.

Fischenich, C., Sotir, R., & Stanko, T., (2001). Assessing Urban Watersheds: The Case of Big Creek, GA. Stormwater. [On-line] Available: wysiwyg://23/http://www.forester. net/sw_001_assissing.html (May 21, 2001)

Franklin, C. (1997). Fostering Living Landscapes. In Thompsen, G.F., & F.R. Steiner (Eds.), Ecological Design and Planning. New York: John Whiley and Sons.

Franklin, C. (1999). Designing as if the Earth Really Mattered. ASLA/LAF Summit White Papers. American Society of Landscape Architects: Washington, DC.

Going Green (2000). [On-line] Available: http:/www.e-architect.com/pia/oct00 roof3.asp (March 28, 2001).

Goldsborough, G,. Gurney, S. (2001). Identifying Potential Contamination Sources on Winnipeg's Urban Streams. [On-line] Available: http://globalforestscience.org/research /Inner-CityFaunaFlora/BC6EF5C3.html

Graham, R. (1984). The Surface Waters of Winnipeg: Rivers, streams, ponds and wetlands, 1874-1984 – the cyclical history of urban land drainage. Unpublished master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Grozeva, I. (1998). Inventory of Systems for Local Management of Stormwater with an Emphasis on Green Roofs. Unpublished masters thesis, International Institute for Industrial Environmental Economics, University of Lund, Lund, Sweden.

Habitat Profiles (1999). [On-line] Available: http:/www.gatewest.net/~cwhp/ habitat/rbf.html (May 7, 2000).

Harrison, D. R. (1991). Greening the City; ecologically based design within an urban context. Winnipeg, MB: Unpublished masters thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Hawken, P. (1993). The Ecology of Commerce. New York: Harper Business.

Hawken, P., Lovins, A., & Lovins, H. (1999). Natural Capitalisim: Creating the Next Industrial Revolution. New York: Little Brown and Company.

Hoffman, D. (1996). Understanding Frank Lloyd Wright's Architecture. New York : Dover Publications.

Hough, M. (1990). Formed by Natural Process. Landscape Architectural Review, 10, 8-11.

Hough, M. (1995). Cities and Natural Process. New York: Routlage Press.

Johnston, J., & Newton, J. (1991). Building Green. London England : London Ecology Unit.

Kaiser, H (1981). An attempt at low cost roof planting. Garten und Landschaft, 99, 30-33

Koeppel, H. D. (1995). Planting greenery on a roof in an extreme site. Anthos, 34, 33-35

Kolb, W., & Schwartz, T. (1986). New Habitats on the Roof – The possibilities for the provision of extensive verdure. Anthos, 25,(1), 4-10.

Koh, J. (1982). Ecological Design: A post-modern design paradigm of Holistic Philosophy and Evolutionary Ethic. Landscape Journal, 1, (2), 76-84.

Kohler, M. (1990). The Living Conditions of Plants on the Roofs of Buildings – A Preliminary Report. In Sukopp, H. (Ed.), Urban Ecology (pp. 33-45).

Kohler, M. (1998). Ecological Analysis of Extensive Green Roofs. Verhandlung der Gesellschaft fur Okologie, 249-255.

Krupka, B.W. (1995). Avoiding Faults and Flaws (English Summary). Garten und Landschaft, 105, (4), 39-40.

Krystek, L. (1998). The Hanging Gardens of Babylon. UMuseum. [On-line]. Available: http://www.unmuseum.org/hangg.htm (January 26, 2001)

Kuhn, M. (1999). Stormwater Management Factsheet 2, Publication of the Green Roofs for Healthy Cities Coalition, Toronto.

Kuhn, M. (1996). Roof Greening. Eco-Architecture, 2, Publication of the Ontario Association of Architects.

Kwik, J. (2000). Gardens Overhead: Rooftop culture sprouts in North American Cities. Alternatives, 26(3), 16-17.

LEED Green Building Green Building Rating System 2.0: Leadership in Energy and Environmental Design (2000). Second Edition. United States Green Building Council

Leopold, A. (1949). A Sand County Almanac and Sketches Here and There. London : Oxford University Press.

Lyle, J. T. (1985). Design for Human Ecosystems. New York : Van Nostrand.

Ludwig, D. (1995). Roofs you can Stroke (English Summary). Anthos, 105(4), 39-40.

Manitoba Capital Region Strategy (MCRS), Partners for the Future. (1995). Manitoba Sustainable Development Coordination Unit. Winnipeg:Canada. ISBN 0-7711-1454-0

Manitoba Conservation. (2001). Technical Draft for Review and Comment: Manitoba Water Quality Standards, Objectives, and Guidelines. (Manitoba Conservation Report Number 2001-01).

Manitoba Natural Resources Water Resources Branch. (1987). Flood Risk Mapping Study Omand's Creek Through the City of Winnipeg. (Report MG-910).

Marsh, W.M. (1997). Landscape Planning Environmental Applications. (3rd Edition.). John Wiley & Sons, Inc.: New York.

McHarg, I. L.(1969). An Ecological Method for Landscape Architecture. In P. Shepherd, & D. McKinley (Eds.), The Subversive Science: Essays Toward an Ecology of Man. Boston: Houghton Mifflin and Company.

McHarg, I.L. (1997). Ecology and Design. In G.F. Steiner, & F.R. Steiner (Eds.), Ecological Design and Planning. New York: John Wiley and Sons.

McHarg, I.L., & F.R. Steiner (1998). To Heal the Earth. Washington, DC: Island Press.

McMarlin, R. M. (1997). Green Roofs: Not your garden variety amenity. Facilities Design and Management, 10, [On-line]. Available: http://www.fdm.com/archive/9/10/ roofing/htm. (September 24, 1998)

Minneapolis Climate Normals 1961-1990. (2001). NOAA Climate Data. [On-line]. Available: http://www.cdc.noaa.gov/cgiin/USclimate/entry.pl?state=MN&itypea=1 &loc.x=274&loc.y=353

Mozingo, L. A. (1997). The Aesthetics of Ecological Design: Seeing Science as Culture. Landscape Journal, 16, (1).

Muller, D.U. (1989). The value of grass roofs for fauna, English Summary. Garten + Landschaft, 99(1), 25

Munson, A.E. (1974). Construction Design for Landscape Architects. New York: Mcgraw-Hill Book Company.

Orr, D. (1992). Ecological Literacy: Education and the Transition to a Postmodern World. New York: SUNY Press.

Osmundson, T. (1999). Roof Gardens: History, design and construction. New York: Norton and Company.

Overview of Current and Planned Research (2001). Green Roofs For Healthy Cites Coalition. [On-line] Available: www.peck.ca/grhcc/research/overview.htm#team (February 28, 2001).

Paddling Omand's Creek. (May 13, 2001). Winnipeg Free Press.

Pearson, D. (1989). The Natural House Book. New York: Simon and Schuster.

Pearson, D. (1994). Earth to Spirit; in search of natural architecture. San Francisco: Chronicle Books.

Peck, S. (Ed.) (1999). The Green Roof Monitor, 1,(1), [On-line]. Available: http://cityfarmer.org/GreenRoof.html. (January, 25, 2000)

Peck, S. (Ed.) (2000). The Green Roof Infrastructure Monitor, 2, (1). Toronto: The Cardinal Group Inc.

Peck, S. (Ed.) (2000). The Green Roof Infrastructure Monitor, 2, (3). Toronto: The Cardinal Group Inc.

Peck, S., Callaghan, C., Bass, B., & Kuhn, M., (Eds.) (1999). Canada Mortgage and Housing Corporation.. Greenbacks from Green Roofs: Forging a new industry in Canada (CMHC file 6585-P085). Toronto: CMHC/SCHL.

Penningsfeld, F., Kurzmann, P., Kalthoff, F., & Fisher, P (1981). Tests on various protective membranes for roof gardens, the results of a four year vegetation study. Garten und Landschaft, 99, 639-647

Peterson, S.L. (2001). Analyzing the green roof: a critical dialogue. Unpublished masters thesis abstract. Iowa State University Department of Landscape Architecture.

Prinz, P., Prinz, E., & Muhle, H. (1981). The biological activation of the urban structure. Garten und Landschaft, 91, 23-29

Rand, H. (1993). Hundertwasser. Italy: Benedikt Taschen Verlag.

Riverbank Management. (2001). City of Winnipeg Planning and Property Development. [On-line]. Available: http://www.city.winnipeh,mb.ca/ppd/riverbank/riverbank2.htm

Schubert, B., & Huber, K. (1995). Kaiseraugust Green Master Plan. Anthos, 34, 15-20

Scrivens, S. (1999). Roof Gardens Specification Guide. Plant User, 25, 2-7.

Schueler, T. (1996). Urban Best Management Practices. Integrating Stormwater into the Urban Fabric. Paper presented at the 1996 Oregon ASLA Awards Program and Conference, Portland, Oregon.

Shulman, K. (2000). The gospel According to Ian McHarg. Metropolis, [On-line] Available: http://www.metropolismag.com/new/aug_content/hrg.htm (January 22, 2001)

Schultz-Bartz, K. (2001). Green Roofs: Stormwater Management from the Top Down. Environmental Design and Construction Magazine, [On-line] Available: http://www.edcmag.com/archives/01-01-4.htm (January, 26, 2001)

Scott, T. (1996). Vegetation. In Welsted, J.E., Everitt, J. Stadel, C. (Eds.). The Geography of Manitoba: Its land and people. Winnipeg: University of Manitoba Press.

Spirn, A. W., (1984). The Granite Garden; urban nature and human design. New York : Basic Books.

Spirn, A. W., (1988). The Poetics of City and Nature; Towards a new aesthetic for urban design. Landscape Journal, v.10 108-126.

Spirn, A.W. (1990). Toward a Unified Vision. Landscape Architecture, 80, (8), 37-41

Stadnyk, E. (1999). Structuring Change; Exploring the Potential of a Greenway at Omand's Creek, Winnipeg. Unpublished master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Stern, A. (1986). The Provision of Verdure on the Credit Suisse Administrative Building, Zurich. Anthos, 25, (1). 11-16.

Stifter, R. (1995). Above the Roofs of Vienna (English Summary). Garten + Landschaft, 105,(4), 39-40

Suzuki, D. (1989). Inventing The Future: reflections on science, technology and nature. Toronto: Stoddart.

Sykes, R.D. (1998). "Stormwater Management", in Harris C.W. & Dines, N.T. Time-Saver Standards for Landscape Architecture: Design and construction data. (2nd Edition). McGraw-Hill Publishing Company: New York.

Teller, J.T. (1984). The Natural Heritage of Manitoba: legacy of the ice age. Winnipeg: Manitoba Museum of Man and Nature.

Thompson, W., (1998). Grass Roofs Movement. Landscape Architecture, 5, 47-51.

Thompson, G.F., Steiner, F.R. (1997). Ecological Design and Planning. New York: John Whiley and Sons.

Tibbets, D., Baker, M. (2000). "CBD-65. Mineral Aggregate Roof Surfacing". Canadian Building Digest. A Publication of the National Research Council of Canada. [On-line]. Available: http://www.nrc.ca/ (February 1, 2001).

Todd, N. J., & Todd, J. (1984). Bioshelters, Ocean Arks, City Farming; ecology as the basis of design. San Francisco: Sierra Club Books.

Valazquez, L. (2001). Green Roof Membrane Waterproofing System.. [On-line] Available: http://www.greenroofs.com/waterproof.htm (July 27, 2001).

Van der Ryn, S., & Cowan, S., (1996). Ecological Design. California: Island Press.

Villager, J. (1986). Green Roofs and Walls – A necessity in the city. Anthos, 25,(1), 1-3.

Watts, M.T. (1961). Reading the Roof Lines of Europe. In P. Shepherd, & D. McKinley (Eds.), The Subversive Science: Essays toward an Ecology of Man. Boston: Houghton Mifflin Company.

Whalley, J. M., (1978). The Landscape of the Roof. Landscape Design, 5, 7-24

White, J. (2001). Green Roof Infrastructure and Preventing Fire Hazards. The Green Roof Infrastructure Monitor, (3), 1.

Wollet, T. & Kimmins, S. (2000). Green Building: a guide to products and their impact on the environment. Suffolk, England : E&F Spon.

ZinCo Roof Gardens (1997). The Green Roof Planning Guide. Holland: Zinco Inc.

APPENDIX A – SURVEY MATERIALS

Neil R. Cunningham
The University of Manitoba
John A. Russell Architecture Building
Department of Landscape Architecture
Winnipeg, Manitoba
R3T 2N2

March 6, 2001

Dear Sir/Madam:

As a graduate student in the department of Landscape Architecture at the University of Manitoba, I am conducting research into the viability and potential costs/benefits of employing green roof technology in the Manitoba Capital Region. I am in urgent need of information pertaining to the performance of green roofs in cool northern climates. I kindly request your much-needed support in completing the enclosed survey.

I am sure that you have other time constraints, however, I anticipate that it should take approximately 20 minutes for you to complete this survey. Please skip any questions that do not apply to your green roof, or that you do not have adequate information on. Enclosed you will find briefing notes, interview questions and an informed consent form regarding this research. I kindly ask that the signed informed consent form be returned with the completed survey.

Should you have any questions regarding this project, I can be reached at XXX-XXX-XXXX. I can also be contacted via e-mail at umcunni2@cc.umanitoba.ca. In the event that I cannot be reached, Professor Charlie Thomsen (project advisor) can be contacted at XXX-XXX-XXXX. Your assistance with this study is greatly appreciated.

Sincerely yours,

Neil R. Cunningham

Encl.

APPENDIX A – SURVEY MATERIALS

A Study of the Viability and Potential Benefits of Extensive Living Roofs in the Manitoba Capital Region with an Emphasis on Stormwater Management

Briefing notes for Interviewees

Introduction

As a graduate student of the department of Landscape Architecture, I am currently engaged in thesis research that explores the suitability of living roof systems to the Manitoba prairie. The members of my thesis committee have approved this thesis research in full. I intend to conduct informal interviews with up to seven people who are familiar with this type of roofing system. Upon receiving approval from the Ethics Committee, I would like to begin interviewing these individuals as soon as possible.

Project Summary

Living roof systems, also known as green roofs, are becoming increasingly common throughout many European cities. Nevertheless, this ecologically based construction technology has yet to be widely adopted within Canada.

The first chapter of this study introduces the scope of the completed research. Chapter Two explores the interrelationships and prevailing attitudes behind our notions of design, ecology, and sustainability. This section then looks briefly at the history of rooftop gardens and green roofs, describes what extensive green roofs are, and differentiates these systems from intensive green roofs.

The second chapter describes the most recent techniques employed in the construction of extensive green roofs, the costs and benefits associated with these systems, and explores the relationship between green roof infrastructure and stormwater management.

The third chapter of this thesis will require formal ethics approval as it involves informal interviews with three individuals who are familiar with structures that have employed extensive green roofing. The facilities studied are all within close proximity to Winnipeg. This case study analysis explores the performance of pre-existing green roofs and assesses their relative merits and weaknesses when compared with traditional methods of roofing.

The participants who will partake in the informal interviews will be asked a series of questions from a pre-designed interview schedule. Any additional relevant information that may arise from the conversation, though not necessarily part of the interview schedule, may be included in the research. Interviews will be conducted over the telephone.

Chapter Four of this thesis discusses the selection criteria and analysis of a selected study site provides the spatial data for the analytical study of the widespread use of green roofs undertaken in Chapter Five. Chapter Five of this thesis will utilize the above-mentioned study site to assess the potential benefits of extensive green roofing as a viable non-structural stormwater management technique. This comparative study identifies any measurable changes in the amount of stormwater runoff discharged into the surrounding watershed. Any potential savings in sub-grade infrastructure costs realized through the use of green roof systems will be identified. The research concludes with an exploration into the policy issues surrounding the use of green roofs and makes suggestions for further research.

Interview Procedures
One interview of approximately one-half hour in length will be conducted over the telephone. If convenient, interviewees can also respond via mail or email. Field notes will be taken during telephone interviews. The interviews will not be tape-recorded. Interviewees will be contacted if any information from the interview requires further clarification. The information collected will be assembled into case study form. Once analyzed and assemble into case study format, the interviewees will be asked to verify the accuracy of the information in its final form.

Confidentiality
The participants will be told that if they choose, their identity will not be revealed. If participants desire anonymity, the data collected from the interview process will be stored in a secure location.

Remuneration
Due to the limited budget of this research, participants will not be remunerated for their time. The findings of this research will, on request, be made available to the participants.

Withdrawal from the Study
Participation from this study is voluntary. Interviewees have the right to withdrawal from the study at any time and/or refrain from answering whatever questions they prefer to omit, without prejudice or consequence.

Complaints
This research has been conducted with prior approval and permission of the Joint Faculty REB and the Department of Landscape Architecture. Any complaints regarding procedure can be reported to the Human Ethics Secretariat (204-474-7122) or the head of the Department of Landscape Architecture (204-474-9915).

DATE: May 31, 2001

SIGNATURE OF
RESEARCHER: ______________________________
Neil R. Cunningham

<u>APPENDIX A</u> – SURVEY MATERIALS

I understand that the University of Manitoba is conducting a study to learn more about the viability and effectiveness of green roof in order to assesses their relative merits and weaknesses. I have read the information sheet on this study. I understand that by participating in this study I am authorizing the University of Manitoba to utilize my responses for the purposes of this research.

CONSENT TO PARTICIPATE

I agree to participate in this study and have been assured that:

- All information I provide will be treated with strict confidentiality
- If I request, I will not be identified personally when the results of the study are presented
- I have the right to refuse to answer any of the questions contained within this study
- I have the right to withdraw the information submitted at any time prior to the completion of this study

PARTICIPANT NAME:____________________________________

NAME OF SUBJECT PROPERTY:____________________________

ADDRESS OF SUBJECT PROPERTY:__________________________

____

____

CHECK APPROPRIATE BOX	**Yes**	**No**
I would like my identity to remain anonymous:	☐	☐
I would like the name of the subject property to remain anonymous:	☐	☐
I would like to receive a copy of the results of this study:	☐	☐

DATE:______________________

SIGNATURE:__________________________________

Please sign this form and return it with the completed survey information. Fax or mail a hard copy of this form to the address at the top of this page. Survey material cannot be included in this study until a signed hard copy of indicating informed consent form is returned.

APPENDIX A – SURVEY MATERIALS

PARTICIPANT SURVEY

Please write your answer in the box provided below each question. Use as much space as required.

(A) GENERAL INFORMATION

1. In what city, province/state, and country is your facility located?

2. What is the name and address of your facility?

3. Is your facility a commercial, industrial, institutional, residential or multi-unit residential building?

4. In what year was your green roof installed?

5. How many square meters/square feet is the surface area of your green roof?

6. Is your green roof flat or sloped?

-- Please turn over --

(B) ROOF DESIGN

7. Was your green roof constructed on top of a new building or was it retrofitted onto a previously constructed building?

8. Did the design of your facility's green roof necessitate the addition of supplemental structural support?

9. Please briefly explain the physical design components of your green roof (membrane type, insulation, soil or substrate depth, etc.).

10. Please describe the plant types used on your green roof. Is this vegetation native to your regional location?

11. Did regional snowfall or rainfall conditions influence the design of your green roof? If so, please explain how.

12. Did cold weather play a role in the design of your green roof? If so, please explain how.

13. Did hot/dry weather play a role in the design of your green roof? If so, please explain how.

14. Were fire precautions a consideration made in the design of your green roof? If so, please describe.

(C) COLD CLIMATE GREEN ROOF PERFORMANCE

15. Has your facility's green roof suffered from defects resulting from membrane failure, improper installation, poor design, improper specification of materials, inappropriate plants or planting techniques, etc)? If so, please explain.

16. Did the vegetation on your facility's roof have any trouble in becoming established? If so, please explain why.

17. In your opinion, has the cold climate of your province/territory/state hindered or adversely affected your green roof? If so, please explain.

18. From your experience, would you maintain that green roofs are suitable for use in cold climates?

-- *Please turn over* --

(D) ROOFTOP STORMWATER RETENTION AND WATERSHED HEALTLH

19. In which watershed is your green roof located?

20. Do you know of the health of your watershed?

21. Do you know of and understand the relationship between buildings, streets, and other impervious surfaces and the health of your watershed?

22. Did rooftop water retention play a significant factor in the decision to install a green roof on your facility?

23. Do you collect/measure runoff from your green roof? If so, have you noticed significant rooftop water retention?

24. Even if you have not taken measurements, does the green roof on your facility appear to retain rainwater? If so, would you say that the roof retains a significant amount?

--Please turn over --

(E) NATURAL ENVIRONMENT

25. Is your facility located in (or adjacent to) an area considered environmentally sensitive?

26. Was the decision to install a green roof on this facility motivated by environmental concerns?

27. Has the green roof on your facility made a significant improvement to the surrounding environment? If so, please explain how.

-- Please turn over --

(F) PUBLIC PERCEPTION

28. Does the general public have good visual access to your green roof?

29. Has the aesthetic appearance of your green roof helped or hindered the public's perception of the tenant?

30. Has the public had a positive or negative reaction toward the aesthetic appearance of your facility's green roof? Please explain.

31. Do you feel that your green roof educates the public about the relationship of buildings, streets and other impervious surfaces and the health of watersheds?

32. How receptive were planning authorities towards the installation of your green roof? Please explain.

-- Please turn over --

(G) COST SAVINGS/LOSSES

33. Was the decision to install a green roof on this facility motivated by potential cost savings?

34. Have there been cost savings associated with the installation of your green roof such as lower heating/cooling costs?

35. Have there been unforeseen costs associated with your green roof. If so, please explain.

-- Please turn over --

(H) CONCLUDING QUESTIONS

36. Do you feel that the benefits outweigh the initial concerns about green roofs?

37. Do you think that problems outweigh the initial enthusiasm about green roofs?

38. How would you rate the overall performance of your green roof?

-- The End, thank you for your time --

APPENDIX A – SURVEY MATERIALS

INTERVIEW PROTOCOL SUBMITTED TO THE JOINT FACULTY RESEARCH ETHICS BOARD

Introduction

As a graduate student of the department of Landscape Architecture, I am currently engaged in thesis research that explores the suitability of living roof systems to the Manitoba prairie. This thesis research has been approved in full by my the members of my thesis committee. I intend to conduct informal interviews with two to four people who are familiar with this type of roofing system. Upon receiving approval from the Ethics Committee, I would like to begin interviewing these individuals as soon as possible.

Project Summary

Living roof systems, also known as green roofs, are becoming increasingly common throughout many European cities. Nevertheless, this ecologically based construction technology has yet to be widely adopted within Canada.

The first chapter of this thesis introduces the scope of the completed research. Chapter Two explores the interrelationships and prevailing attitudes behind our notions of design, ecology, and sustainability. This section then looks briefly at the history of rooftop gardens and green roofs, describes what extensive green roofs are, and differentiates these systems from intensive green roofs.

The second chapter describes the most recent techniques employed in the construction of extensive green roofs, the costs and benefits associated with these systems, and explores the relationship between green roof infrastructure and stormwater management.

The third chapter of this thesis will require formal ethics approval as it involves informal interviews with three individuals who are familiar with structures that have employed extensive green roofing. The facilities studied are all within close proximity to Winnipeg. This case study analysis explores the performance of existing green roof systems and assesses their relative merits and weaknesses when compared with traditional methods of roofing. The participants who will partake in the informal interviews will be asked a series of questions from a pre-designed interview schedule. Any additional relevant information that may arise from the conversation, though not necessarily part of the interview schedule, may be included in the research. Interviews will be conducted over the telephone.

Chapter Four of this thesis discusses the selection criteria and analysis of a selected study site provides the spatial data for the analytical study of the widespread use of green roofs undertaken in Chapter Five. Chapter Five of this thesis will utilize the above-mentioned study site to assess the potential benefits of extensive green roofing as a viable non-structural stormwater management technique. This comparative study identifies any measurable changes in the amount of stormwater runoff discharged into the surrounding watershed. Any potential savings in sub-grade infrastructure costs realized through the use of green roof systems will be identified. The research concludes with an exploration into the policy issues surrounding the use of green roofs and makes suggestions for further research.

Research Instruments
With the exception of an informed consent form, the participants will not be given any materials.

Study Subjects
I intend to interview between two and four subjects. I will contact these people over the telephone or through e-mail and ask them if they would be willing to participate. Participants in this study are not from vulnerable populations, nor will they require any extra measures.

Informed Consent
Participants will be informed about the project in general and the relevance of their knowledge to my thesis research. An informed consent form (attached) will be provided to the participants through mail, fax or e-mail. The participants are to read the consent form before they agree to participate. Prior to being interviewed, participants will be asked to verbally indicate their willingness to participate. No confidential records will be consulted for the purpose of this study.

Deception
There will be no deliberate withholding of essential information or the provision of deliberately misleading information about the research or its purposes.

Feedback/Debriefing
Participants will be sent the minutes of their informal interview once the information has been recorded. Participants will be asked to validate that the information accurately reflects their opinions.

Risks and Benefits
There will be no risks to the individuals being interviewed or to third parties. Participants will be informed that they can refuse to answer any questions or end the interview at any time. There is no physical risk involved.

Inducements
There will be no tangible inducements to the participants in this study. Participants will be informed about the study's purpose and the practical implications of the study. Benefits to the participants will be the satisfaction of informing the further development of environmentally sustainable construction practices. Participants will be informed that they will have access to the results of this research.

Anonymity and Confidentiality
Participants will be informed that their identity will not be revealed. Owing to the nature of the subject matter, confidentiality is not an issue in this research. Interview data will be stored in a secure location and will be destroyed on completion of the work.

Information Gathering
Subjects will not be compensated for their participation. The informal interview will not exceed thirty minutes. Subjects will be informed that they will have access to the completed research. The subjects will benefit from the knowledge that their expertise will further our understanding of sustainable building practices.

UNIVERSITY OF MANITOBA | Office of the President

Office of Research Services
244 Engineering Building
Winnipeg, MB R3T 5V6
Canada
Telephone: (204) 474-8418
Fax: (204) 261-0325

APPROVAL CERTIFICATE

04 April 2001

TO:	**Neil R. Cunningham** Principal Investigator	**(Advisor C. Thomsen)**
FROM:	**Wayne Taylor, Interim Chair** Joint-Faculty Research Ethics Board (JFREB)	
Re:	**Protocol #J2001:022** **"A Study of the Viability and Potential Benefits of Extensive Living Roofs in the Manitoba Capital Region "**	

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

APPENDIX B - SURFACE AREA SUMMARY CALCULATIONS

Description of Zone Data	*Zone*	*Qty.*	*Area sq./ft*	*Area Sum sq./ft*	*Area Sum ac.*
Wal-Mart roof area (flat, gravel)	1	1	124,600	124,600	2.8608
Wal-Mart parking and paving	1	1	118,627	118,627	2.7237
Wal-Mart outdoor garden centre (paved)	1	1	13,540	13,540	0.3109
Wal-Mart parking lot planted islands	1	7	291	2,037	0.0467
Wal-Mart parking lot planted islands	1	5	97	485	1.1114
Wal-Mart and Proposed development creek bed (path not incl.)	1	1	76,078	76,078	1.7468
Wal-Mart and Proposed development crushed limestone path	1	1	4,034	4,034	0.0928
Proposed development roof area (flat, gravel)	1	1	9,000	9,000	0.2066
Proposed development roof area (flat, gravel)	1	1	9,500	9,500	0.2181
Proposed development roof area (flat, gravel)	1	1	9,500	9,500	0.2181
Proposed development roof area (flat, gravel)	1	1	12,000	12,000	0.2755
Proposed development parking and paving	1	1	183,229	183,229	4.2069
Proposed development parking lot planted islands	1	2	296	538	0.0124
Proposed development parking lot planted islands	1	1	2,583	2,583	0.0593
Proposed development parking lot planted islands	1	1	2,638	2,638	0.0606
Proposed development parking lot planted islands	1	1	861	861	0.0198
Proposed development parking lot planted islands	1	1	355	355	0.0081
Proposed development parking lot planted islands	1	1	1,658	1,658	0.3081
Proposed development parking lot planted islands	1	1	344	344	0.0079
Winners retail roof area (flat, gravel)	2	1	51,690	51,690	1.1869
Penningtons/Tootsies retain roof area (flat, gravel)	2	2	11,875	11,875	0.2727
Polo Park Inn and new addition roof area (flat, gravel)	2	2	75,219	75,219	1.7270
Polo Park Inn beer store roof area (sloped, tin)	2	2	2,456	2,456	0.0564
Polo Park Inn/Winners/Retail parking and paving	2	2	310,687	310,687	7.1334
Polo Park Inn parking lot planted islands	2	10	97	970	0.0223
Polo Park Inn parking lot planted islands	2	1	1,772	1,772	0.0407
Polo Park Inn parking lot planted islands	2	1	1,507	1,507	0.0346
Polo Park Inn parking lot planted islands	2	1	689	689	0.0158

APPENDIX B - SURFACE AREA SUMMARY CALCULATIONS

Description of Zone Data	*Zone*	*Qty.*	*Area sq./ft*	*Area Sum sq./ft*	*Area Sum ac.*
Polo Park Inn/Winners/Retail creek bed	2	1	73,270	73,270	1.6823
Home Depot roof area (flat, gravel)	3	1	104,025	104,025	2.3885
Home Depot outdoor garden centre paved	3	1	21,082	21,082	0.0500
Home Depot parking and paving	3	1	274,634	274,634	6.3056
Home Depot parking lot planted islands	3	7	258	1,803	0.0415
Home Depot parking lot planted islands	3	6	517	3,102	0.0712
Home Depot parking lot planted islands	3	1	2,906	2,906	0.0667
Home Depot parking lot planted islands	3	1	431	431	0.0099
Home Depot parking lot planted islands	3	2	538	1,076	0.0247
Home Depot parking lot planted islands	3	1	258	258	0.0059
Home Depot parking lot planted islands	3	1	215	215	0.0049
Home Depot parking lot planted islands	3	1	581	581	0.0133
Home Depot grass island behind building	3	1	2,692	2,692	0.0618
Home Depot creek bed (not including limestone path)	3	1	58,047	58,047	1.3328
Home Depot crushed limestone path	3	1	5,247	5,247	0.1205
Chapters Bookstore roof (flat, gravel)	3	1	22,299	22,299	0.5120
Sportmart roof (flat, gravel)	3	1	26,104	26,104	0.5993
Montana's Cookhouse roof area (flat, gravel)	3	1	5,188	5,188	0.1191
Montana's Cookhouse patio	3	1	1,390	1,390	0.0319
Kelsey's Restaurant roof area (flat, gravel)	3	1	4,994	4,994	0.1147
Kelsey's Restaurant patio	3	1	1,560	1,560	0.0358
Grass area surrounding restaurants	3	1	15,302	15,302	0.3513
Chapters/Sportmart/Restaurants parking and paving	3	1	177,842	177,842	4.0832
Chapters/Sportmart/Restaurants parking lot planted islands	3	5	225	1,125	0.0258
Chapters/Sportmart/Restaurants parking lot planted islands	3	6	309	1,854	0.0426
Chapters/Sportmart/Restaurants parking lot planted islands	3	2	351	702	0.0161
Chapters/Sportmart/Restaurants parking lot planted islands	3	2	250	500	0.0115
Chapters/Sportmart/Restaurants parking lot planted islands	3	1	675	675	0.0155

APPENDIX B - SURFACE AREA SUMMARY CALCULATIONS

Combined Sewer Data	*Zone*	*Qty.*	*Area sq./ft*	*Area Sum sq./ft*	*Area Sum ac.*
Wal-Mart area draining into combined sewer (70% roof, 30%paved)	1	1	82,340	82,340	1.8905
Proposed development, area draining into combined sewer (80% parking, 20% roof)	1	1	37,090	37,090	0.8516
Winners area draining into combined sewer (70% roof, 30% parking)	2	1	22,605	22,605	0.5190
Polo Park Inn draining into combined sewer (50% roof, 40% parking, 10% grass)	2	1	123,250	123,250	2.8298
Home Depot area draining into combined sewer (60% roof, 30% paving, 10% grass) note entire roof drains into combined sewer	3	1	170,000	170,000	3.9032

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 1 Area Summary

Total area (acres)	Total area draining into Omand's Creek (acres)	% Of zone draining into Omand's Creek	Total area draining into combined sewer (acres)	% Of zone draining into combined sewer
14.4945	11.7425	82	2.7421	18

Zone 1 Pre-development Runoff as Derived using the Rational Method Under Three Different Storm Scenarios

Surface	Coefficient of runoff	Surface area (acres)	Rainfall 5yr storm (inches/hr.)	5yr storm surface runoff (cfs.)	Rainfall 20yr storm (inches/hr.)	20yr storm surface runoff (cfs.)	Rainfall 50yr storm (inches/hr.)	50yr storm surface runoff (cfs.)
Grass (5-10% slope, clay and silt loam)	.36	1.7468	1.65	1.04	2.20	1.38	2.50	1.57
Grass (no slope, clay and silt loam)	.50	12.7477	1.65	10.52	2.20	14.02	2.50	15.93
Sub-totals	---	**14.4945**	---	**11.56**	---	**15.40**	---	**17.50**

Zone 1 Runoff Resulting from Surfaces at Grade as Derived using the Rational Method Under Three Different Storm Scenarios

Surface (other than roofs)	Coefficient of runoff	Surface area (acres)	Rainfall 5yr storm (inches/hr.)	5yr storm surface runoff (cfs.)	Rainfall 20yr storm (inches/hr.)	20yr storm surface runoff (cfs.)	Rainfall 50yr storm (inches/hr.)	50yr storm surface runoff (cfs.)
Concrete/ Asphalt/ Patio	.95	7.2415	1.65	11.35	2.20	15.13	2.50	17.20
Grass (5-10% slope, clay and silt loam)	.36	1.7468	1.65	1.04	2.20	1.38	2.50	1.57
Grass (no slope, clay and silt loam)	.50	0.00	1.65	0.00	2.20	0.00	2.50	0.00
Crushed Limestone (compacted)	.70	0.0928	1.65	0.11	2.20	0.14	2.50	0.16
Parking Islands (Flat treed, clay and silt loam)	.30	1.6343	1.65	0.81	2.20	1.09	2.50	1.22
Sub-totals	---	10.7154	---	13.31	---	17.74	---	20.15

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 1 Existing Rooftop Runoff and Rooftop Runoff under Simulated Green Roof Conditions as Derived using the Rational Method Under Three Different Storm Scenarios

Roof Surfaces	*Coefficient of runoff*	*Roof surface area (acres)*	*Rainfall 5yr storm (inches/hr.)*	*5yr storm surface runoff (cfs.)*	*Rainfall 20yr storm (inches/hr.)*	*20yr storm surface runoff (cfs.)*	*Rainfall 50yr storm (inches/hr.)*	*50yr storm surface runoff (cfs.)*
(A) Standard roof System	.95	3.7791	1.65	**5.92**	2.20	**7.90**	2.50	**8.98**
(B) Green roof system	.40	3.7791	1.65	**2.49**	2.20	**3.33**	2.50	**3.78**

Zone 1 A Comparison of Existing Site Runoff, Site Runoff Under Simulated Green Roof Conditions and Site Runoff under Pre-development Conditions

Land Use Scenario	*5yr storm (cfs.)*	*5yr storm, 82% runoff into creek (cfs.)*	*5yr storm, 18% runoff into combined sewer (cfs.)*	*20yr storm (cfs.)*	*20yr storm, 82% runoff into creek (cfs.)*	*20yr storm, 18% runoff into combined sewer (cfs.)*	*50yr storm (cfs.)*	*50yr storm, 82% runoff into creek (cfs.)*	*50yr storm, 18% runoff into combined sewer (cfs.)*
(A) Runoff from standard roof system (calculated above) plus runoff from sources at grade (previous page)	**19.23**	15.77	3.47	**25.64**	21.02	4.62	**29.13**	23.89	5.24
(B) Runoff from green roof system (calculated above) plus runoff from sources at grade (previous page)	**15.80**	12.96	2.84	**21.07**	17.28	3.79	**23.93**	16.62	7.31
(C) Pre-development rates of runoff (as calculated on previous page)	**11.56**	9.48	2.08	**15.40**	12.63	2.77	**17.50**	14.35	3.15

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 2 Area Summary

Total area (acres)	***Total area draining into Omand's Creek (acres)***	***% Of zone draining into Omand's Creek***	***Total area draining into combined sewer (acres)***	***% Of zone draining into combined sewer***
12.1721	8.8233	72	3.4488	28

Zone 2 Pre-development Runoff as Derived using the Rational Method Under Three Different Storm Scenarios

Surface	***Coefficient of runoff***	***Surface area (acres)***	***Rainfall 5yr storm (inches/hr.)***	***5yr storm surface runoff (cfs.)***	***Rainfall 20yr storm (inches/hr.)***	***20yr storm surface runoff (cfs.)***	***Rainfall 50yr storm (inches/hr.)***	***50yr storm surface runoff (cfs.)***
Grass (5-10% slope, clay and silt loam)	.36	1.7623	1.65	1.00	2.20	1.33	2.50	1.51
Grass (no slope, clay and silt loam)	.50	10.4898	1.65	8.65	2.20	11.54	2.50	13.11
Sub-totals	---	**12.1721**	---	**9.65**	---	**12.87**	---	**14.82**

Zone 2 Runoff Resulting from Surfaces at Grade as Derived using the Rational Method Under Three Different Storm Scenarios

Surface (other than roofs)	***Coefficient of runoff***	***Surface area (acres)***	***Rainfall 5yr storm (inches/hr.)***	***5yr storm surface runoff (cfs.)***	***Rainfall 20yr storm (inches/hr.)***	***20yr storm surface runoff (cfs.)***	***Rainfall 50yr storm (inches/hr.)***	***50yr storm surface runoff (cfs.)***
Concrete/ Asphalt/ Patio	.95	7.1334	1.65	11.15	2.20	14.87	2.50	16.90
Grass (5-10% slope, clay and silt loam)	.36	1.6823	1.65	1.000	2.20	1.33	2.50	1.51
Grass (no slope, clay and silt loam)	.50	0.00	1.65	0.00	2.20	0.00	2.50	0.00
Crushed Limestone (compacted)	.70	0.00	1.65	0.00	2.20	0.00	2.50	0.00
Parking Islands (Flat treed, clay and silt loam)	.30	0.1134	1.65	0.03	2.20	0.07	2.50	0.08
Sub-totals	---	**8.9291**	---	**12.18**	---	**16.27**	---	**18.49**

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 2 Rooftop Runoff and Runoff under Simulated Green Rooftop Conditions as Derived using the Rational Method Under Three Different Storm Scenarios

Roof Surfaces	*Coefficient of runoff*	*Roof surface area (acres)*	*Rainfall 5yr storm (inches/hr.)*	*5yr storm surface runoff (cfs.)*	*Rainfall 20yr storm (inches/hr.)*	*20yr storm surface runoff (cfs.)*	*Rainfall 50yr storm (inches/hr.)*	*50yr storm surface runoff (cfs.)*
(A) Standard roof System	.95	3.243	1.65	**5.08**	2.20	**6.77**	2.50	**7.70**
(B) Green roof system	.40	3.243	1.65	**2.14**	2.20	**2.85**	2.50	**3.24**

Zone 2 A Comparison of Existing Site Runoff, Site Runoff under Simulated Green Roof Conditions and Site Runoff under Pre-development Conditions

Land Use Scenario	*5yr storm (cfs.)*	*5yr storm, 72% runoff into creek (cfs.)*	*5yr storm, 28% runoff into combined sewer (cfs.)*	*20yr storm (cfs.)*	*20yr storm, 72% runoff into creek (cfs.)*	*20yr storm, 28% runoff into combined sewer (cfs.)*	*50yr storm (cfs.)*	*50yr storm, 72% runoff into creek (cfs.)*	*50yr storm, 28% runoff into combined sewer (cfs.)*
(A) Runoff from standard roof system (calculated above) plus runoff from sources at grade (previous page)	**17.89**	12.88	5.00	**23.04**	16.58	6.45	**26.19**	18.86	7.33
(B) Runoff from green roof system (calculated above) plus runoff from sources at grade (previous page)	**14.32**	10.31	4.01	**19.12**	13.77	5.35	**21.73**	15.64	6.09
(C) Pre-development rates of runoff (as calculated on previous page)	**9.65**	6.95	2.7	**12.87**	9.27	3.60	**14.82**	10.67	4.15

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 3 Area Summary

Total area (acres)	*Total area draining into Omand's Creek (acres)*	*% Of zone draining into Omand's Creek*	*Total area draining into combined sewer (acres)*	*% Of zone draining into combined sewer*
16.3920	12.4888	76	3.9032	24

Zone 3 Pre-development Runoff as Derived using the Rational Method Under Three Different Storm Scenarios

Surface	*Coefficient of runoff*	*Surface area (acres)*	*Rainfall 5yr storm (inches/hr.)*	*5yr storm surface runoff (cfs.)*	*Rainfall 20yr storm (inches/hr.)*	*20yr storm surface runoff (cfs.)*	*Rainfall 50yr storm (inches/hr.)*	*50yr storm surface runoff (cfs.)*
Grass (5-10% slope, clay and silt loam)	.36	1.3328	1.65	0.79	2.20	1.06	2.5	1.20
Grass (no slope, clay and silt loam)	.50	15.1592	1.65	12.42	2.20	16.57	2.5	18.82
Sub-totals	---	**16.3920**	---		---	**17.63**	---	**20.02**

Zone 3 Runoff Resulting from Surfaces at Grade as Derived using the Rational Method Under Three Different Storm Scenarios

Surface (other than roofs)	*Coefficient of runoff*	*Surface area (acres)*	*Rainfall 5yr storm (inches/hr.)*	*5yr storm surface runoff (cfs.)*	*Rainfall 20yr storm (inches/hr.)*	*20yr storm surface runoff (cfs.)*	*Rainfall 50yr storm (inches/hr.)*	*50yr storm surface runoff (cfs.)*
Concrete/ Asphalt/ Patio	.95	10.4388	1.65	16.36	2.20	21.82	2.50	24.79
Grass (5-10% slope, clay and silt loam)	.36	1.3328	1.65	0.79	2.20	1.05	2.50	1.20
Grass (no slope, clay and silt loam)	.50	0.4131	1.65	0.34	2.20	0.45	2.50	0.52
Crushed Limestone (compacted)	.70	0.1205	1.65	0.14	2.20	0.18	2.50	0.21
Parking Islands (Flat treed, clay and silt loam)	.30	0.3532	1.65	0.17	2.20	0.23	2.50	0.26
Sub-totals	---	12.6584	---	17.80	---	23.77	---	26.98

APPENDIX C – ZONE CALCULATIONS FOR STUDY SITE

Zone 3 Existing Rooftop Runoff and Rooftop Runoff under Simulated Green Roof Conditions as Derived using the Rational Method Under Three Different Storm Scenarios

Roof Surfaces	*Coefficient of runoff*	*Roof surface area (acres)*	*Rainfall 5yr storm (inches/hr.)*	*5yr storm surface runoff (cfs.)*	*Rainfall 20yr storm (inches/hr.)*	*20yr storm surface runoff (cfs.)*	*Rainfall 50yr storm (inches/hr.)*	*50yr storm surface runoff (cfs.)*
(A) Standard roof System	.95	3.7336	1.65	**5.85**	2.20	**7.80**	2.50	**8.87**
(B) Green roof system	.40	3.7336	1.65	**2.46**	2.20	**3.29**	2.50	**3.73**

Zone 3 A Comparison of Existing Site Runoff, Site Runoff Under Simulated Green Roof Conditions and Site Runoff under Pre-evelopment Conditions

Land Use Scenario	*5yr storm (cfs.)*	*5yr storm, 76% runoff into creek (cfs.)*	*5yr storm, 24% runoff into combined sewer (cfs.)*	*20yr storm (cfs.)*	*20yr storm, 76% runoff into creek (cfs.)*	*20yr storm, 24% runoff into combined sewer (cfs.)*	*50yr storm (cfs.)*	*50yr storm, 76% runoff into creek (cfs.)*	*50yr storm, 24% runoff into combined sewer (cfs.)*
(A) Runoff from standard roof system (calculated above) plus runoff from sources at grade (previous page)	**23.65**	17.97	5.68	**31.57**	24.00	7.57	**35.85**	27.25	11.25
(B) Runoff from green roof system (calculated above) plus runoff from sources at grade (previous page)	**20.26**	15.40	4.86	**26.23**	19.93	6.30	**30.71**	23.34	7.37
(C) Pre-development rates of runoff (as calculated on previous page)	**13.21**	10.04	3.17	**17.63**	13.40	4.23	**20.02**	15.22	4.80

APPENDIX D – SUGGESTED PLANTS FOR USE ON EXTENSIVE GREEN ROOFS IN THE MANITOBA CAPITAL REGION

Wildflowers/sedum

BOTANICAL NAME	NOTES / NATURAL HABITAT
Achillea millefolium	Native to Europe & Asia, Naturalized here in North America. Once established, it's very drought tolerant
Allium bivalve	Native to Granite Outcrops
Centaurea cyanus	Annual; Coneflower or Bachelor's Button.
Chrysantheum leucanthemum	Native to Asia, Ox-Eye Daisy needs well-drained soil.
Coreopsis lanceolata, tinctoria	Also *C. auriculata, grandiflora, major, nundata, rosea, verticillata*
Cosmos bipinnatus, sulphureus	Native to Mexico, a self-seeding annual
Echinacea purpurea	Also *E. pallida paradoxa*
Gaillardia aristata, pulchella	Annual & perennial, Firewheel likes well drained soil
Hieracium venosum	Native to the granite outcrops
Liatris microcephala	Gayfeather is native to granite outcrops
Oenothera speciosa	Showy Primrose is a native of North America east of the Mississippi; also *O. fruticosa, tetragona*
Opuntia drummondii	Prickly Pear is a native of granite outcrops
Phlox drummondii	Also *P. carolinacomplex, glaberrima, maculata, paniculata, pilosa. P divaricata* native to eastern North America
Potentilla canadensis	Native of granite outcrops
Rudbeckia hirta	Black Eyed Susan; also *R. fulgida, lacinat, maxima, nitida, triloba*
Sedum pusillum, smallii	Native of granite outcrops
Senecio smallii, tomentosa	Ragwort is native of granite outcrops; also *S. aureus, glabellus, obovatus*, native to eastern North America
Solidago spp.	Goldenrod is native plant with numerous spp., such as *S. nemoralis, odora, pintorum, rigida, rugosa, sempervirens, speciosa*, and *ulmifolia*
Tradescantia hirsutocaulis	Spiderwort is native to granite outcrops
Yucca filamentosa	Native of granite outcrops

(Adapted from Valasquez, 2001)

APPENDIX D – SUGGESTED PLANTS FOR USE ON EXTENSIVE GREEN ROOFS IN THE MANITOBA CAPITAL REGION

Grasses

BOTANICAL NAMES	NOTES / NATURAL HABITAT
Andropogon ternarius, virginicus	Found on granite outcrops, abandoned fields; widely distributed, many species
Koeleria cristata	June grass; Grassland rocky ridges and open forests
Bouteloua curtipendula, hirsuta	Sideoats Grama and Hairy Grama are native to the Texas area
Panicum lithophilum, and *spp.*	Switchgrass is native to North America; also *P. virgatum*
Festuca ovina	Fescue; Found in open woods, clearings grasslands and rocky slopes

(Adapted from Valasquez, 2001)