Instrumental Landcapes
Sustainable Strategies for Wetland Development

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

As a result of widespread urban development over the past two decades, global wetlands are disappearing at an alarming rate. This thesis develops a series of strategies for protecting wetland ecosystems from the ecological consequences that cascade through an ecosystem as a result of such development.

This thesis is based on the paired assumptions that ecosystems represent networks of linked processes that operate across both local and global scales, and that the ecological integrity of any ecosystem can be maintained (a) only if the physical integrity of an ecosystem's constituent processes is maintained, and (b) only if damage occurring at one ecological scale is prevented from affecting processes occurring at another. Thus, the strategies proposed here are multi-scalar and implemented at both the scale of the site and at the broader watershed scale.

The strategies developed in this thesis focus on maintaining the physical integrity of the local wetlands as a means of protecting the processes that occur within the broader wetland ecosystem. The thesis proposes that wetland sites might be best protected from the effects of urban development by implementing a series of landscape interventions that provide the ecosystem with the means to reorient itself in new ecological relationships. Instead of attempting to recreate and control a complex set of conditions by imposing a deterministic architectural solution on the site, this strategy seeds new processes and new structural relationships such that the ecosystem reorganizes itself according to its own structural logic and grows into new stable relationships according to conditions that arise out of those processes. Because this approach generates a series of self-sustaining processes, human intervention is minimized beyond the initial stages.

The stategies proposed here will be explored in the context of proposals recently announced by oil companies to develop ecologically sensitive wetland sites located on the Athabasca River in north-eastern Alberta.

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Since the 1980s, the rate at which wetlands have been disappearing has doubled in some cases (Iran, the US, most of South America), and tripled in others (China, India). In the last century the total area of the world's wetlands were reduced by sixty percent. Almost seventy percent of that disappearance occurred in the last thirty years. During those same thirty hyears, population increase remained stable.

In other words, though population increased more slowly than it had during the seventy years preceding, wetland destruction as a result of urbanization increased at a rate of over two hundred percent during the same period.

Over the past one hundred years, fifty percent of the world's wetlands have been destroyed as a result of urbanization or transfer to agricultural uses. Though population growth remained relatively stable during the last thirty years, the rate of wetland destruction as a result of urbanization doubled, and half of all wetland losses that occurred in the last century occurred between 1980 and 2006.

At the current rate, half of the world's remaining wetlands may be destroyed in less than three decades.

Introduction

It would be an understatement to say that the urban development of a wetland environment creates localized ecological damage. The urbanization of wetlands is, in fact, catastrophic in its effects upon both local and global ecologies.

Wetlands carry out several important functions within the global ecosystem. In addition to providing habitat for countless plant and animal species – seven hundred species of bird in North America, fifty percent of which are dependant on the Albertan boreal alone[1] – and ensuring species richness and diversity within those habitats, global wetlands are instrumental in providing three fundamental and irreplaceable ecological roles.

Global wetlands play a predominant role in keeping the noxious effects of greenhouse gas emissions in check[2]. Covering only six percent of the earth's surface they slow global warming by storing twenty percent of our terrestrial carbon. This is an amount equal to all of that held in the atmosphere today. In Alberta alone, eleven percent of the world's CO_2 is held trapped in the northern boreal forests and wetlands[3].

Moreover, global wetlands act as terrestrial water filters, purifying all of the water that passes through them, removing toxins from groundwater and moderating the quality of water residing in adjacent aquifers[4]. In Canada, the Albertan wetlands not only store winter run-off so that it can be harvested by farmers in the spring, but they also purify the majority of groundwater that is used to water the crops grown in that province[5]. The Albertan farming industry depends upon the moderating role these wetlands play in regulating and purifying groundwater flow through northern Canada.

In addition, because they store such a high quantity of water (the Albertan wetlands are ninety-five percent liquid by volume, which is to say, they are only slightly more dense than homogenized milk), they create vast heat sinks across broad territories. These massive landscapes of fairly stable temperature play a major role in regulating global weather systems, precipitation patterns, air mass flow, and in the Northern Hemisphere, drive the Jet Stream[6]. Recent research has also shown that these wet landscapes play a major role in moderating air quality, and that as a result of the massive volumes of water vapour that they are always in the process of evaporating, not only improve air quality locally, but siphon pollutants out of air-borne vapour as well[7].

The wholesale destruction of massive percentages of global wetland could have devastating effects, then, upon our global weather patterns, our air quality, our respiratory health, and the quality of water that we drink and the food that we eat. In Alberta, specifically, wetland destruction could lead to toxins being passed into the same aquifer that provides farmers with the water they use to irrigate their crops[8]. Also, it could lead to a reduction in the amount of water stored in that aquifer during the shoulder seasons, and consequentially, could lead to a drop in available water in the spring[9]. More devastating and immediate, however, would be the effects of the wholesale release of unprecedented volumes of carbon dioxide and methane into the atmosphere[10].

Given the statistics cited above, the issue of wetland destruction is obviously a pressing one. Over the past four decades, wetland urbanization has increased steadily and alarmingly. Recent figures show that over the last century, sixty percent of the world's lagoons and marshes have disappeared[11]. In Canada, wetland losses in the latter half of the last century have been staggering: seventy percent of the marshes and swamps that line the shores of the Great Lakes-St. Lawrence System have disappeared; seventy-one percent have been destroyed in the Prairie Provinces; eighty percent of the Pacific coast estuarine wetlands have been lost. In Manitoba, seventy-one percent of wetlands were lost between nineteen twenty-eight and nineteen eighty-two[12].

In the US, losses have been just as high. Along the coastal shores of Florida, and up the Mississippi River, ocean front property and riverside housing development have led to massive losses of once abundant wetland territory. The numbers vary, but all indications suggest that the rate of wetland loss in the southern US is on par with that in Canada[13].

The recent housing boom, and massive growth in cities adjacent to Tampa and Miami, and South Carolina and Maryland, may have pushed the numbers even higher[14].

In Mexico and South America the numbers have not been well documented by authorities, but the study of archival maps of early European settlement suggests that Mexico may have lost thirty-five percent of its original wetland area[15]. And though they had remained untouched until relatively recently, South American wetlands have been devastated over the course of the last thirty years. Conservative estimates place South American losses somewhere between eighty and eighty-eight percent of their wetland totals.

In Europe, average peatland loss has been in excess of fifty percent over the last two centuries. In the Netherlands, Germany, Spain, Greece, Italy, France, and parts of Portugal, wetland losses exceeding that number have been reported over the past two decades. In the UK, it is estimated that twenty-three percent of coastal estuaries, forty percent of wet grassland, and fifty percent of regional salt-marshes have been lost since Roman times.

Meanwhile in Thailand, the Philippines, and Singapore, wetland losses have topped twenty-two percent, a now typical sounding seventy-eight percent, and ninety-eight percent respectively. Credible researchers claim that the number in Thailand actually exceeds eighty-two percent, but official records are incomplete. There are claims that losses in West Malaysia total eleven percent, Indonesia eighteen percent, and Malaysia seventy-one percent[16]. China officially claims that only thirteen percent of its wetlands were urbanized over the last fifteen percent years, but this number is fiercely contested[17].

In Australia ninety percent of the original wetland area has disappeared. And though it was never a wet country, it is now reported that Israel has lost one hundred percent of its original wetlands, though that number remains unconfirmed[18].

Most famous of all documented losses are those of Iraq under Saddam Hussein's urbanization policies in the mid nineteen eighties. Here, records proudly document the destruction of that country's once fertile Tigris/Euphrates River valleys to the tune of ninety to ninety-seven percent.

The Canadian context is particularly precarious because in addition to the typical architectural and agricultural pressures that are being brought to bear on wetland resources all across the globe, the Albertan boreal wetland faces the additional threat of resource development.

Though this thesis does not touch upon oil sands development and the threat it poses to Alberta's northern wetlands, it is worth nothing that of Alberta's three hundred and eighty thousand square kilometres of Boreal forest – much of which is wetland – one hundred and forty-four square kilometres are leased to oil sands developers[19]. Covering an area larger than Newfoundland, larger than the Florida panhandle, and roughly sixty percent of the size of the United Kingdom, Oil Sands leases in Alberta's Boreal wetlands represent an area roughly one-fifth the size of the province. And were those leases to be developed in the coming years, the destruction would be unparalleled, and the long-term environmental effects catastrophic.

The work that follows is concerned with developing strategies that would provide the means to protect wetland sites from inevitable urban development. It attempts to find means that not only protect the physical integrity of the local wetlands, but also maintain the operation of the ecological processes that operate within the site prior to its development, and to maintain the systemic processes of the greater ecosystem of which the local ecology is a part. The context of this design is the proposed development of an isolated town of fifteen thousand people along the banks of the northern Athabasca River.

The ecological consequences of urban development, whether they result from damage brought about by construction, or by the daily activity of urban life, do not affect the local system alone, but have repercussive effects that impact every scale of the ecosystem of which they are a part. By definition, ecosystems operate as operate as networks, and because the destruction of a portion of a networked process affects the function of the whole, any attempt to mitigate the damaging effects of wetland development cannot operate at the local scale alone. Rather, it must take into account the far larger intermediate and broad watershed scales with which these local systems connect, and be deployed across the breadth of those linked ecosystem scales. Only a method that tackles these ramifications at each of those scales can begin to deal with the ecological repercussions of urban development of sensitive ecosystems.

The means for achieving this end are discussed in what follows. Ultimately, the goal is to provide means to develop a wetland site sustainably by providing the means for maintaining the physical integrity of the processes operating within the local ecosystem, and thereby allowing ecologies at every scale of the system to continue to carrying out their ecological functions despite being compromised.

As is increasingly being shown in the work of many landscape ecologists[20], the models that we have used to rebuild wetlands over the past two decades may not be achieving the ends their authors had hoped for. In fact, many of these older models are failing to live up to the expectations that were set of them with regards to rebuilding wetland ecologies.

Obviously there have been successes in rebuilding wetlands. Toronto's Leslie Spit, for example, is widely regarded as a successful attempt at rebuilding a natural landscape[21], and recently a handful of studies have cited successes in a few other projects within Ontario[22]. That said, a growing body of research is beginning to appear that suggests that over the long term, landscape regeneration is not being as successful as initial successes would have promised.

If regeneration attempts have failed, a survey of the relevant literature begins to reveal why this might be so. Wetland structural conditions are too complex to be duplicated[23], structural relationships are too precarious[24], and intervention timelines are too long. Repeatedly, landscaped features interact in unforeseen combinations and in case after case mitigated landscapes evolve in ways that are both unpredictable[25] and that cannot be accommodated by the rigid conditions implicit in their design. Moreover mitigation attempts are often too dependant upon ongoing management and human intervention, and not surprisingly, as economic conditions and politics change these projects suffer from lack of attention[26]. In almost every instance where a wetland is manipulated, the change that follows is often for the worse[27]. Ironically, landscape is proving to be incredibly resilient to our attempts to mitigate the negative effects of our own interventions.

The three decade pursuit of planted wastewater systems has shown that we can recreate wetland conditions in controlled circumstances[28]. but this does not mean that we have the means to repair the damage that urban development creates on a large-scale wetland site and its adjacent systems; the conditions that interact with each other to create a wetland scenario in the wild are too complicated, and not nearly understood.

Given the inherent complexities that define ecosystem relationships, and the degree to which their constituent elements are linked together at every scale, we must assume that any intervention on our part is going to do unwitting damage. This being the case, we cannot arrogantly assert that we are capable of mitigating wetland destruction through the implementation of novel strategies. Instead, our goal must be to neutralize to as great a degree as possible, the impact that our intervention will have upon the site, while simultaneously ensuring that we are not forcing solutions that cannot accommodate change onto the local system.

The essence of a solution, then, must be the creation of the incomplete; the preparation of a site for the setting in motion of new conditions. To that end, what we propose below will not be an intervention so much as an infrastructure upon which natural processes can operate and adapt, one that will foster the creation of new and potentially surprising relationships.

The complexity of a wetland system precludes our being able to duplicate it. Operating in a series of different dimensions simultaneously[29], its health is dependant upon the connections between living and non-living phenomenon – between local populations and morphological, geological, and hydrological conditions – and across scales that are both physical and temporal. That said, we can play off of its natural resilience[30] – its ability to absorb disturbances – to create a situation that allows it to reorganize itself along new lines that are just as stable as the previous ones. A series of thoughtful design interventions, ones that reflect an understanding of the ecosystem's structural integrity, and that foster the processes at work within that ecosystem, could create conditions that allow an ecologically compromised landscape to readapt itself to new conditions (what Lance Gunderson refers to as "an alternate stable state") and to enter into new relationships with different ecosystem processes[31] within the local ecology.

To that end, a series of thoughtfully designed infrastructural interventions could provide a wetland protection from urban development if those interventions allowed the wetland to reorganize itself in relation to new conditions according to its own structural and biological logic. Instead of attempting to recreate an overly complex system, and instead of forcing the landscape to adhere to a set of conditions that would not accommodate unimagined changes within the system over time, such a design could put in place structural elements that would generate a context in which the system could grow into new relationships that it itself defined, and to find a new stable state on its own[32].

If, as designers, we wish to promote ecologically supportive solutions, we need to conceptualize design as more than environmental manipulation, and something closer to process design; the orchestration of a series of complex, sometimes contraindicated, often messy forces and operations. If we wish to participate in the caretaking of the systems that surround us, we have to propose more than discrete architectural responses, more than planning responses, and more than simple programmatic juxtaposition. We have to engage design as the planning of the interaction of a series of complex systems.

Ultimately, the strategies presented here accomplish more than simply saving a system by setting it aside in what will inevitably become a disconnected (i.e. park) setting. This is full integration achieved by creating overlaps between pre-existing conditions and new processes that are defined in such a way as to allow for natural development and change. In other words, rather than creating an overarching program for maintaining a discrete ecosystem as an isolated phenomenon, this approach embeds processes within a system in such a way that adaptation to new conditions, and growth and change, remain possible. More than just a collection of management principles whose function is determined by predetermined top-down causal relationships, it is an open-ended system of processes, adapting in response to feedback from external inputs, and as a result, it is capable of negotiating new conditions as a condition of its ability to evolve and grow in tandem with the broader system of which it is a part.

What makes this approach both valuable and unique is that it attempts to put in place strategies that would mitigate ecological damage before it occurs. Moreover, this approach does not set finite boundaries on the limits of influence that processes have within a system, but rather, conceptualizes phenomenon as networked processes whose boundaries are porous and whose actions have ramifications across many ecological scales. Effects upon the environment are understood as being non-linear and open, and thus, the strategies developed are open-ended, flexible, and robust enough to adapt to inevitable ecological and systemic change.

The thesis that follows is divided into two parts: "Part One: Site" and "Part Two: Intervention". Part One is further broken down into four chapters. In Chapter One we describe and position the site, and provide a context for the intervention. In Chapter Two we summarize wetland fundamentals by describing wetland types, the complexity that defines wetland structure, the systemic conditions that define wetlands function, and the role that wetlands play within the local and global ecological system. In Chapter Three we describe the difficulties associated with wetland construction and typical construction techniques used to overcome these. Also included is a discussion of the ecological impacts caused by wetland urbanization.

In Chapter Four we conduct a site analysis and describe the regional characteristics that define local morphology and hydrological characteristics. The goal here is to clarify not only the specific physical conditions that describe the site, but to understand the complex relationships that interact in order to create those particular conditions, so that when it comes time to plan our intervention, its design accommodates the forces that shape the site and that determine its operation. To that end, this Chapter presents an analysis that highlights the interactions that take place between the geological, morphological, and hydro-geological forces operating both locally and globally.

Chapter Four is divided into two parts. Part One provides an analysis of the large-scale geographical features that shape local site conditions; namely morphology and topography, subsurface conditions, and geological and hydrological behaviour. In Part Two, local characteristics are analyzed and described in a series of analysis drawings. The Chapter concludes with a series of diagrams that define the buildable limits of the site.

If Part One of this thesis determines the nature of the forces that work within and around the site to create specific conditions, "Part Two: Intervention" develops the series of principles that will be used to negotiate these and to define an approach to building within the wetland.

Part Two begins with Chapter Five. In this chapter we propose a series of principles and strategies that can be implemented in order to protect a wetland from the ecological consequences of urban development. The Chapter is divided into two parts. In the first part, we discuss the principles that facilitate wetland viability, and that limit our ability to design prescriptive interventions as a means of mitigating the damage caused by urban development. Following this discussion we propose a series of 8 goals that guide us in developing specific responses for developing this site sustainably. These 8 goals are based on a synthesis of recent ecological research and practice, and ultimately it is these goals that direct us toward designing an intervention that responds to and reflects the site's unique ecological character.

As per the conclusions that guide the development of this strategy – namely, that effective sustainable strategies must not impose deterministic solutions but rather must allow for system growth and change – the intervention will be less a design solution than an approach to creating a series of procedures that, once deployed, initiate new processes within the landscape. It reflects the conclusion that a landscape intervention is sustainably sensitive only if it protects both the structural integrity of the site locally, and the processes that are carried out in that location. As expected, the strategy proposed in Chapter Five is both local and global in scale and execution.

The Thesis ends with some Concluding Remarks including a discussion of project implications and limitations, and suggestions regarding possible avenues for further research and development along the lines of the ideas proposed in this thesis.

Footnotes

[1] Jarvenpa and Brumbach, 2003.

[2] Moser, Prentice, and Frazier 1996

[3] United Nations, 2009.

[4] Tarnocai, 2006.

[5] Apps, 1993.

[6] Charman, 2002.

[7] Bjornlund, Henning, 2006.

[8] Becker, Ahang, Cihlar, Ileka, and MacGregor, 2006.

[9] Pietroniro and Demuth, 2006.

[10] Tarnocai, 2006.

[11] United Nations, 2009.

[12] Dahl, 1993; United Nations 2009; Cutlac and Weber, 2006.

[13] Ibid.

[14] Ibid.

[15] Except where noted, the following international numbers all derive from United Nations, 2009.

[16] Gaoming, 2008.

[17] Lee, and Lopez 2002.

[18] Moser, Prentice, and Frazier 1996.

[19] Government of Alberta, 2006.

[20] For example, see Gunderson's work, the NRC's "Compensating for Wetland Losses", Karaus's riverbed reconstruction studies (Karaus, Alder, and Tockner (2005)), and attempts by Syncrude to regenerate large swaths of landscape strip-mined by their operations at the Firebag Oil Development in Northern Alberta; as one ecologist assessed it, the results resembled natural landscape less than "a golf course where the lawnmower is broken - a hard land with a little pond at the bottom. And only about 2% of the wetland area has been reclaimed" (Schindler, 2004).

[21] It is notable that its success is attributed to its hands-off approach (NRC 2001).

[22] Locky et al 2005.

[23] Ewer's examination (Ewer, 1972) of the complex relationships that exist between animal/ insect populations and the degree to which those relationships govern the growth and viability of populations of differing species within the same ecosystem, suggests that with any tampering of a landscape comes unavoidable and disruptive (if not destructive) impact upon animal/insect

populations within that ecosystem. See also Davies-Colley (2000), Hanowski, Wolter & Niemi (2000), and Ayres (1998).

[24] Take, for example, the case of the parafluvial pond. The para-pond is a key structural element of a wetland site. Usually short-lived, these ponds form along the banks of bodies of water, adjacent to a marsh or a bog, and create a series of conditions that promote certain biotic processes that give life to the wetland. They provide shelter for insects or fish, and thus provide food to terrestrial life. They modify pressure differentials along the bank in incredibly subtle ways, and thus enhance the ability of a wetland to draw water to itself. They promote bankful tides and the drawing of water into a marsh. They amplify the riverbank's ability to draw water into itself and into adjacent soil (a measure that ecologists refer to as a drawdown curve; another fundamental structural element).

And yet, parafluvial ponds are so fragile that ecologists describe instances where the moving aside of a riverside branch has caused a para-pond to evaporate within hours. Of course, on a micro-scale, this kind of structural damage is hardly noticed. But one can see the danger inherent in larger scale activity occurring adjacent to a group of these ponds.

[25] As Urban and Rhoads (2003) point out, there is a "considerable disparity between the efficacy of human actions and the efficacy of recovery processes" within landscape systems.

[26] de Geus, 1999.

[27] Many studies have suggested that the slightest re-engineering of a riverbank would lead to devastating changes within adjacent wetlands, completely realigning its relationship with structural features at the river's edge. Schwimmer, Pizzuto, and Collins have all recorded surprising results in regards to the delicate relationship that exists between a riverbank height and the adjacent marsh. Collins has gone so far as to claim that "changes of 2cm to bank height create widespread changes to marsh area".

Schwimmer's work goes so far as to conclude that a wetland's survival may be dependant upon the slightest wave action at the riverbank (ironically, his work suggests that wave action helps to maintain the marsh's riverside structure. All of this to say that time after time after time, ecologists are concluding that the nature of the relationships that create wetland sites are incredibly delicate, incredibly balanced, and incredibly complex.

[28] Izembart, Helene and Bertrand Le Boudec, 2003.

[29] As Gunderson describes it: "Ecological organization can be viewed as a hierarchy in which each hierarchical level has its own distinct spatial and temporal attributes. A critical feature of such hierarchies is the asymmetric interaction that occurs between all levels… The hierarchies are not static but are transitory structures maintained by interaction across scales… operating simultaneously in longitudinal, lateral, vertical, and temporal dimensions" (Gunderson, 2002).

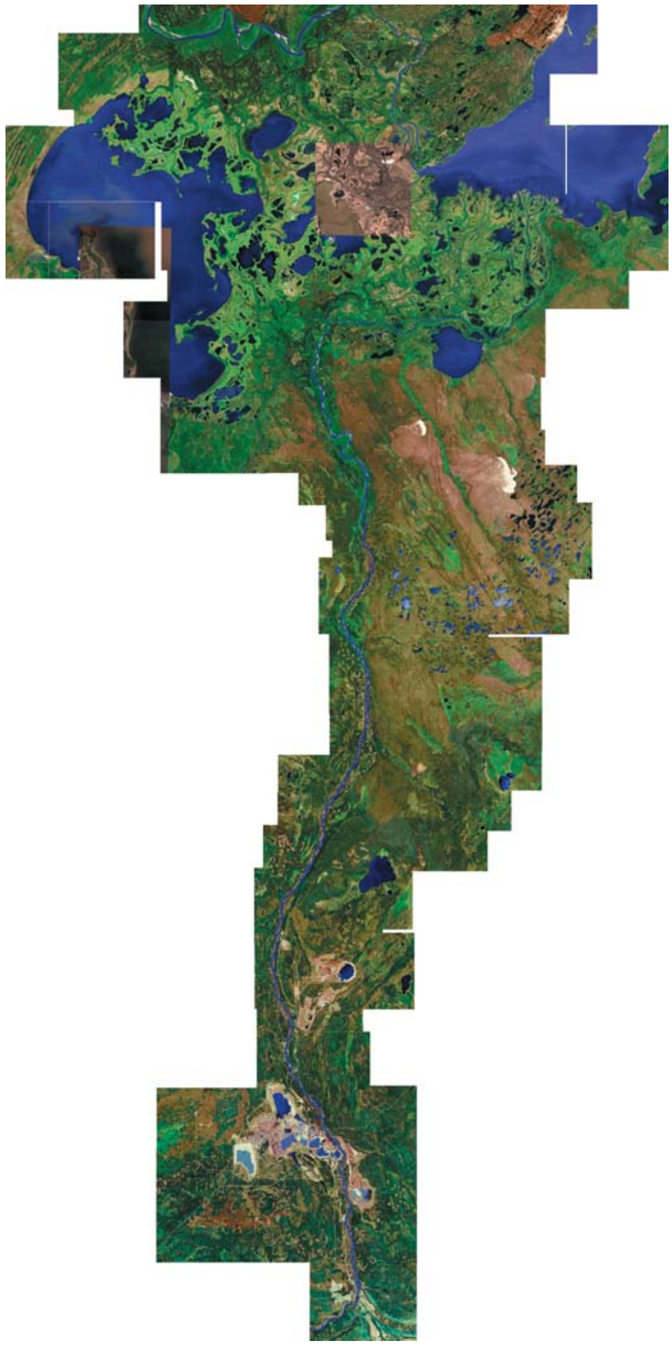
[30] Gunderson and Pritchard, 2002.

[31] See Gunderson's work on adaptive capacity – an ecosystem's ability to absorb disruption and if

necessary readapt itself to a new ecological condition and processes (Gunderson, 2002).

[32] Specifically, the following design does so by promoting functional overlaps within similarly scaled operations within the ecosystem; by creating new structuring processes that cut across scales within the system; by maximizing sources of landscape renewal and reformation within the local ecology; and by providing for and creating connections to multiple sources of ecological capital within broad swaths of the greater landscape.

part one: Site



chapter one

Site Context

In Chapter One we introduce the project and describe the context within which the intervention occurs. Specifically we describe site conditions typical to the Boreal Forest (including climatic and landscape characteristics, and site-specific hydrological conditions), and position the site within the Athabasca Watershed and in relation to a variety of unique geographical, geological, and hydrological phenomena.

Recent developments in the economics of global oil production have created boom conditions in the Alberta oil sands region. As a result of increased production and the need to open newer and larger oil production sites located further from the established centre at Fort McMurray Alberta, locally invested oil interests have announced a number of plans for developing new housing projects for sites located along the northern Athabasca River. Though the specifics have not been detailed by investors, most proposals cite a twenty-five year investment in these new locations, an expected work force of four thousand employees, and a growing population of families and support staff. Projections vary in their estimates but most assume the development of a fully sufficient community within three to five years of the initial ground-breaking.

For the purposes of this thesis, town size was calculated at fifteen

Facing page, fig. 1.1:
The Athabasca Watershed, scale approximately 1/1 000 000.




thousand people. Demographics upon which the programming of the urban development is based were extrapolated from a careful study of similarly sized towns developed in similar contexts throughout Canada and the world. Most notably, Fort McMurray provided a model from which to extrapolate population projections, male-to-female ratios, family size and demographics, and programme areas for building types (including schools, hospitals, retail and commercial space), and for industrial land use and parkland were extrapolated from those of Fort McMurray.

Though none of the investor projections pinpoint a specific location for urban development, current leases for petroleum exploration in Alberta extend along both banks of the Athabasca River from Fort McMurray north to the town of Fort Chipewyan on Lake Athabasca. Within this area, certain site-specific conditions make the banks of the Athabasca River the most ideal location for urban development. The site chosen for this thesis is located one hundred and eighty kilometres north of Fort McMurray (six hundred and fifteen kilometres north of Edmonton), approximately three-quarters of the distance between Fort McMurray and Fort Chipewyan (sixty kilometres to the north). It is incredibly remote, and accessible only by air or water.

The landscape adjacent to the Athabasca River north of the Fort McMurray is unique in that it is characterized by a high incidence of wetlands, and unlike typical topography, much of the ground within the area designated for potential development is nothing more than a mass of highly absorptive decomposing plantlife (peat) floating on top of vast seas of subsurface water[1]. The water table is usually found at or near its surface, and though appearing solid, much of the ground adjacent to the Athabasca River is simply a floating blanket of plantlife, varying in depth, density, and consistency[2].

Where wetland does give way to more solid surface, the landscape is an aggregate of glacially deposited gravel and till, an inconsistent and

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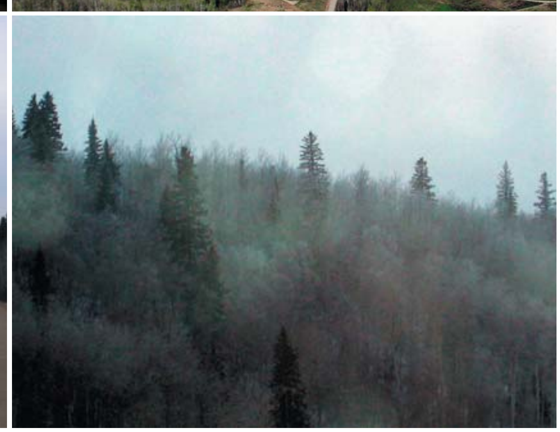
Facing page, figs. 1.2 - 1.5:
Images of the Athabasca Watershed and surrounding wetlands.



non-structural blanket of shifting sand layered above floating biomass and intermittent bedrock, and covered by a thin layer of topsoil[3]. The glacial till forms plains and small hills, and is in a state of constant and violent evolution; prone to collapse, hills give way suddenly, and riverbank landscapes are carried off wholesale by an energetic and voluminous form of erosion referred to as avulsion[4].

The combination of peat formations and structurally unsound till plain creates a landscape of unique topographical features. Bedrock is difficult to locate, and when found its depth can reach as much as two hundred metres[5]. The landscape is undercut by pools of subsurface water, and large channels (measuring as much as two hundred metres width and extending for tens of kilometres[6]) flow beneath sand and peat. Sinkholes commonly appear, byproducts of gaping pockets formed within subsurface rock formations[7]. The abundance of water creates unique up- and down-swelling hills and riven chunks of terrain referred to as hummocks and bummocks. And the meandering Athabasca River creates convoluted ripples of terrain (referred to as braid bars and transgression lineaments) that slowly migrate across territories, pulling the river with it and folding marshland into strands and ropes of twisted hills[8].

Road construction is prohibitively expensive and almost impossible in this region. As a result, communities north of Fort McMurray are not connected by roads, and only one highway runs north of that city to provide access to the oil developments at Syncrude and Bitumount. It peters out just north of this second site, less than seventy-five kilometres north of the city. In the winter, ice roads provide the only access to all regions north of Bitumount.

Relative to south-western Ontario, north-eastern Alberta is a place of extreme climatological conditions. Though warm in the summer months, temperature fluctuations between night and day in both winter and summer are steep. The growing season is very short, the shoulder

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Clockwise from top left: an aerial view of the Athabsca Delta illustrates the expanse of marshes and the extent of saturation. Fort Mcmurray looking north along the Athabasca River. Boreal Forest outside of Fort McMurray. Highway 63 running north towards the oil sands.

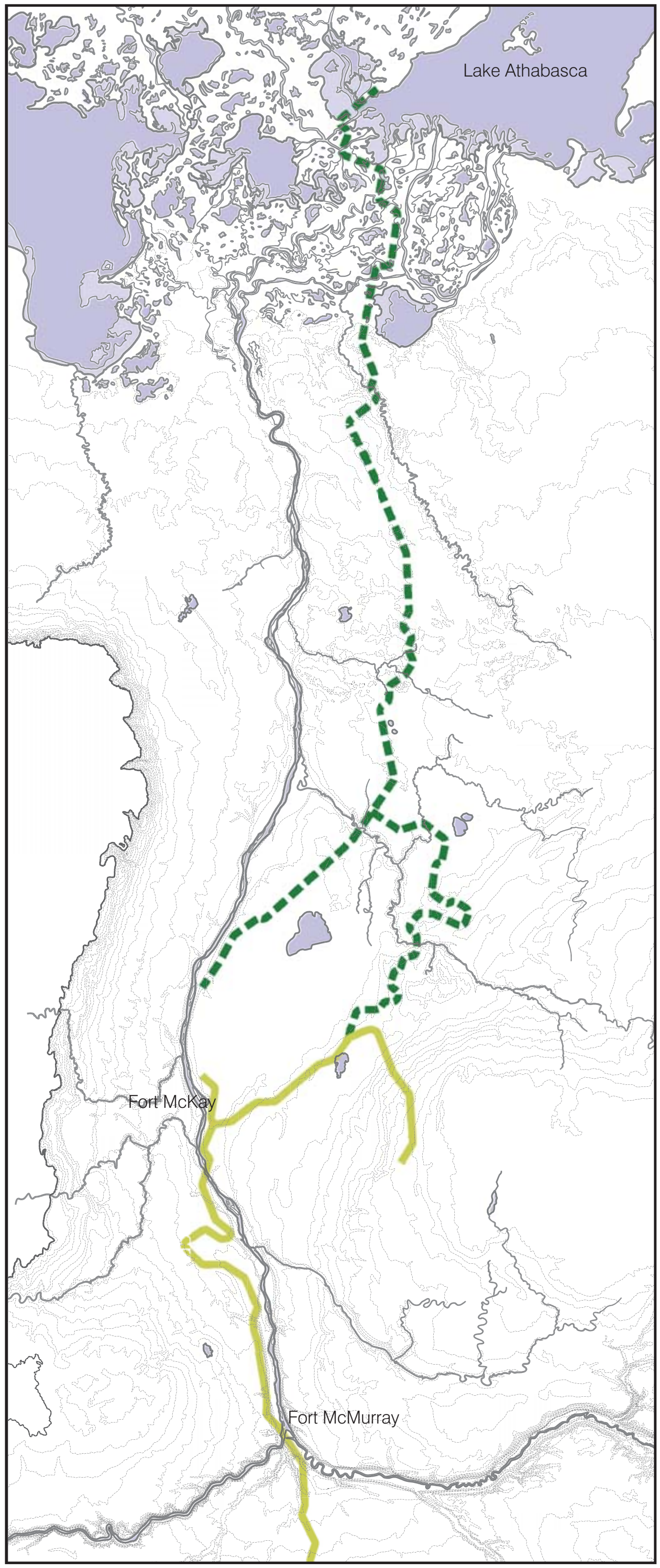

FORT CHIPEWYAN
WINTER ROAD
TRAVEL AT OWN RISK
NO GAS OR SERVICES
NEXT 210 km

seasons are abrupt, and extreme shifts characterize both the beginning and the end of winter. Though starting late in the year, spring comes with a sudden shift in temperatures, a short but intense period of thawing and flooding, and a quick increase in temperature as warm summer air ushers in the growing season. Summer is short, maximum temperatures rarely rise above twenty-one degrees, and average only fourteen degrees. Fall, though warmer than in Ontario, begins in late August and ends by mid-October. The first month of winter is typically mild, but by mid-November the temperature may drop to as low as forty degrees below zero, and February temperatures can dip as low as seventy below zero[9].

The site chosen for this thesis is located within two distinct ecological communities: the Athabasca Watershed and the Boreal Forest[10]. Running more than fifteen hundred kilometres, the Athabasca River is the longest river wholly contained within Alberta, the longest undammed river in the Prairie Provinces, and the second largest by volume. The river basin drains one hundred and fifty-nine thousand square kilometres before joining the Peace River to form the Mackenzie River Basin and flowing north into the Arctic Ocean[11].

The Athabasca Watershed both influences, and is influenced by, a majority of the climatological, topographical, and ecological characteristics that define this region. For example, both the amount of water retained by local aquifers, and the rate and degree of flooding within the region are influenced by the rate and volume of water carried by the River[12]. The potential for damage to urban centres in the south as a result of flooding is a major concern, as is the maintenance of adequate aquifer levels since both of these have a direct impact on the agricultural and petroleum

Facing page, figs. 1.10 - 1.15:
Travel north of Bitumount is limited by ground conditions that make road construction an impossibility. Access is available only during the winter months when an ice road makes the terrain navigable. Clockwise from top left: the end of the road; Highway 63 north of Bitumount. Tractors grade a frozen lake to prepare it for the winter. Trucks head north carrying supplies to the isolated oil and diamond communities of the far north. Two isoloated roads head north across the rugged terrain.

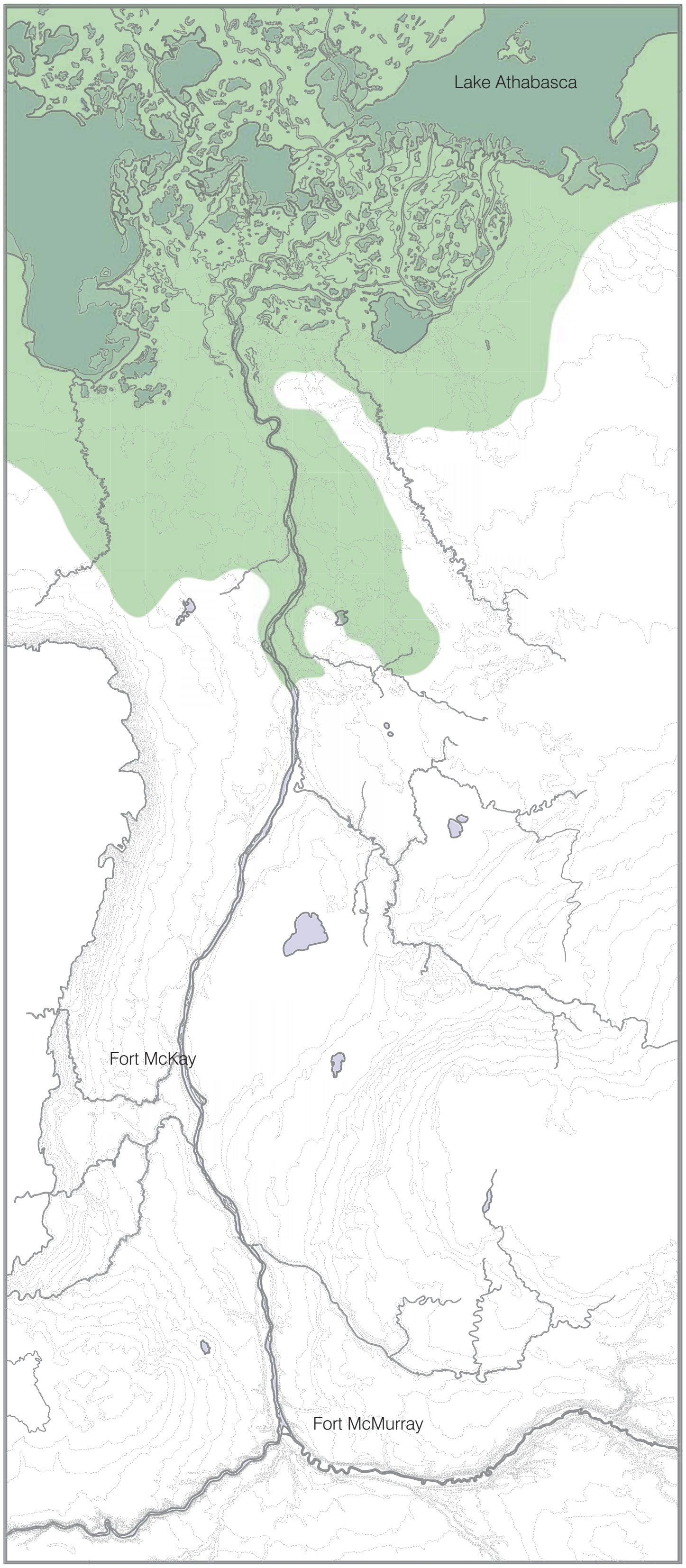

Lake Athabasca
Fort McKay
Fort McMurray

industries within the province[13]. Significantly the River controls neither of these processes on its own, but is directly influenced by the role played by local wetlands[14]. Spring thaws and subsequent flow rates are the direct result of annual snow-melt rates. But both snow retention and snow-melt are governed by ground temperatures, and these, in turn, are determined by wetland temperatures and saturation rates[15]. Topographical saturation also influences subsurface water flow, which controls aquifer retention capabilities and water table height. Moreover, flooding is controlled by the ability of local wetlands to retain water through saturation[16]. The rate of precipitation itself is governed by groundwater temperatures and the effects that these have on air mass circulation and precipitate surcharge (i.e. the ability to create precipitation, and the volume of precipitation created).

The annual pattern of wetland flooding along the northern Athabasca River also plays a direct role in maintaining the biological productivity of the River Delta[17] (and thus the wetland's ability to mediate flooding directly influences wetland biological diversity). Moreover, annual flooding is vital in maintaining wetland structure[18], wetland habitats (which, as we will see below, constitute their own kind of wetland structure, and thus have a direct impact on the maintenance of a healthy wetland), and wetland temperatures (key in driving precipitation cycles and controlling global warming)[19]. It goes without saying, of course, that annual flood patterns also directly affect construction, determining whether or not a site can be developed, and if so, determining whether or not flood-control measures must be put in place. The River, then, plays a central role in organizing not only daily patterns of rural and urban life, but it affects industry and wildlife, as well as globally scaled natural cycles.

The site is also located within the Boreal Forest[20], a nearly

Facing page, fig. 1.16:
Roads running north from Fort McMurray. The solid line represents Highway 63, coming to an end just north of Bitumount. The dotted line shows one of many ice road routes that head north over the winter. Scale is approximately 1/1 000 000.

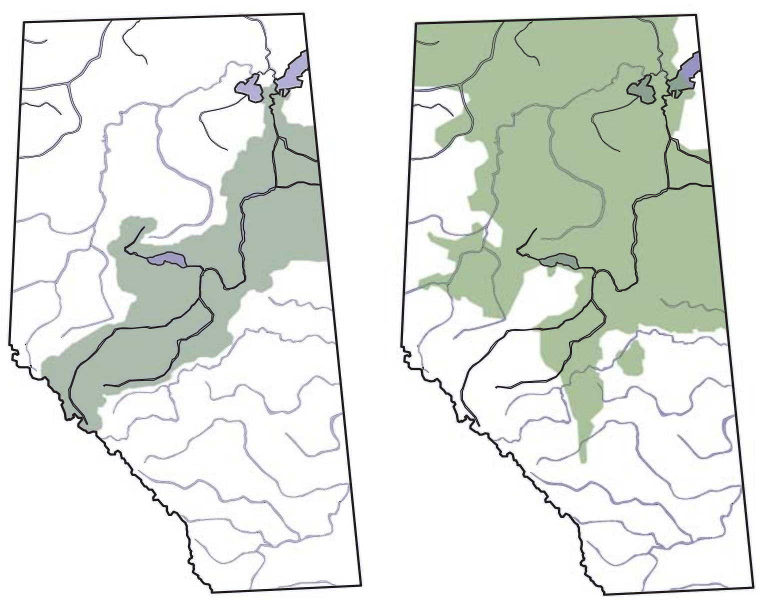

Lake Athabasca
Fort McKay
Fort McMurray

continuous belt of coniferous trees stretching across northern Canada and Russia. Occupying most of northern Alberta, the forest is a mosaic of plant and animal communities inhabiting varying environmental conditions Though topographically, climatologically and biologically diverse, changes between ecological communities within the Boreal are both gradual and subtle, and thus, distinctions between ecological zones are difficult to determine[21]. Based upon these distinctions, the Boreal Forest is divided into six sub-regions. Our site is located in the Lower Boreal Highlands.

As with the Athabasca Watershed[22], the Boreal Forest plays a central role in defining the character of the local ecosystem. The Boreal Forest and the wetlands found within it form a structurally integrated baseline for the operation of both ecosystems[23], and any damage to one invariably impacts the other[24]. Thus, the development of a relatively small site within the structurally integrated ecological whole will directly affect the continued growth of the larger system itself; namely, the forest, its ability to maintain itself, and the operation of the ecological functions within that system[25]. In turn, the continued function of these processes, will have a direct bearing on the continued functioning of the broader wetland system in other locations within the forest (and not necessarily directly linked to our site)[26]. The catastrophic effects of urban development, then, will not only affect the site alone, but will have a direct impact on how well the those systems connected to both the Watershed and the Forest itself function.

As stated above, the urban development of wetland sites creates catastrophic ecological damage. In this chapter we not only positioned the site within a provincial context (in terms of geography and urban development patterns), but we described the specifics that govern architectural development within this region (by describing features such as sectional composition and local site conditions) such that we could begin

Facing page, fig. 1.17 :
A map showing the extent of wetlands within the Athabasca Watershed. Scale is approximately 1/1 000 000.



to understand the forces at work here, and propose means for developing the site. Additionally, we began to introduce those ideas that will provide the framework which will guide us in developing architectural principles that allow us to build in the wetland. However, because we cannot develop a site-specific and ecologically sensitive intervention without first understanding the functions that a wetland provides, and without first understanding which functions are damaged by urban development, we must now discuss wetland processes, the manner in which wetlands operate, and the physical relationships that govern that operation.

Facing page, figs. 1.18 - 1.19:
Left: the Athabasca watershed. Right: extent of the Boreal Forest.

Footnotes

[1] Mossop and Flach, 2003.

[2] The Albertan wetlands are 95% liquid by volume, which is to say that they are only slightly more dense than homogenized milk (Charman, 2002).

[3] Beilman, 2001, Collella, 1995.

[4] Geological Survey of Canada, 2004.

[5] Dolton and Hannah, 2006.

[6] Andriashek and Meeks, 1993; Rayner and Rosenthal, 2008.

[7] Government of Alberta, 2007.

[8] Lee, Jo, and Chu, 2006; Naruse and Masuda, 2006.

[9] Government of Alberta, 1969.

[10] It is important to note that though we are currently describing site conditions in order to position the project within a specific geographical context, and to describe the functions and phenomenon that influence and constitute the site, an understanding of the site's relationship to the Boreal Forest and the Athabasca Watershed will play a much larger role in informing the ideas developed in this thesis as this work progresses. Not only does this discussion provide us with an understanding of the local forces and functions that influence the activities that occur at the site, and the processes that constitute its behaviour, but it also it highlights the ecological importance of the site as something that is not only governed by and shaped by its position within a larger ecological framework, but as something that governs and shapes the system of which it is a part. In other words, this discussion reinforces the argument developed below that a wetland is a connected system. Thus, when we discuss the ecological impact of wetland development, we already understand that it proliferates across ecological communities at many different scales.

But more significantly than this, understanding these relationships as processes within processes, as systems operating across scales, and as highly structured, irregularly ordered three-dimensional entities that maintain influences across communities, regions, temporal zones and geographical scales, informs the manner in which we will observe the ecological communities and processes discussed in the coming chapters. Ultimately, it is this conceptualization that will directly influence the nature of the principles developed in the final chapter (with specific regards to the manner in which they operate to mitigate (or even, that they mitigate) urban development, and that they do so by integrating within and around the organizational properties of the processes already operating at the site).

[11] Alberta Environment, 2005 (1), (2), (3).

[12] Prepas and Mitchell, 1990.

[13] Griffiths and Woynillowicz, 2003.

[14] Kowalczyk, and Hicks 2003.

[15] Bjornlund, Henning, 2006.

[16] Government of Alberta, Environment, 2007.

[17] This suggests that seasonal and annual flooding patterns must be maintained in order to both maintain the level of productivity within the watershed, and also to maintain the ecological processes that are influenced by that flooding at different scales within the system. This is significant because it suggests that the key to maintaining wetland structural properties is to maintain ecological processes occurring on the site (as will be discussed in Chapters Two and Four).

[18] Charlton, 2007.

[19] Cairns, 1995.

[20] Beckingham and Archibald, 1996.

[21] Or put differently: distinctions between states of relative influence between ecological communities are not distinct. Which is to say, the ecological relationships that occur within the Boreal Forest, and the maintenance of communities found there, and of ecological processes occurring within its borders, are both closely linked and interconnected, and cross-scalar; blending physical boundaries across a large territory.

[22] As described in comments made above.

[23] One could argue, in fact, that at some levels there is no distinction between the functional capabilities of either system, and thus there is only one ecosystem.

[24] Olewiler, 2004.

[25] Sanderson and Harris, 2000.

chapter two

Understanding Wetlands

In Chapter One we positioned the site within a geographical context, described site conditions that affect construction in this region, and introduced the ideas that will frame our attempt to develop principles for developing wetlands. However, since we cannot develop an intervention without first understanding the functions that a wetland provides, and that are damaged by urban development, Chapter Two describes wetland processes, the manner in which they operate, and the physical relationships that allow those operations to take place. Moreover, it conceptualizes these processes as "structural" phenomenon.

Chapter Two fulfils one other function: because very little data exists that describes the site's geographical and hydrological properties, determining the character of these features is possible only if we first establish a baseline understanding of wetland characteristics and types. In subsequent chapters we will cross-reference this baseline against known features from the site and thereby determine the hydrological, geological, and topographical character of the large and small scale forces operating there. Arriving at such an understanding is key to developing an intervention since it is only by doing so that we will be able to make determinations about the character of the site, and from that point forward develop site-specific strategies for sustainable urban development.






Chapter Two fulfils four functions. First, it provides a brief overview of wetland types and characteristics. In the absence of source materials that describe the geological, morphological, and hydrological properties of the site, this material will be used in Chapter Four to determine site characteristics that will define where construction can take place.

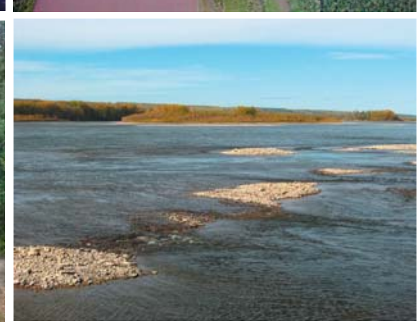
Secondly, since we cannot develop strategies that integrate with landscape processes if we do not first understand the processes occurring within the given system, and since we cannot attempt to offset ecological damage if we do not first understand the nature of that damage, Chapter Two provides a description of wetland functions. Also, because we cannot develop methods to offset wetland damage unless we understand the (technical) means by which wetlands are capable of carrying out these functions, Chapter Two examines the physical characteristics and components that define those processes, describes the manner in which landscape features interact and operate in order to create specific landscape conditions and processes, and argues that these features and the relationships that they define are in fact responsible for generating wetland processes; that they are in fact "structural" devices: ordering, generative features that determine the nature of the processes that occur within the landscape, and about which those processes are organized[1].

This notion that landscape features and processes act as structural components is a key formulation, since it is only by understanding the relationships between these features and processes – in fact, it is only by understanding that the processes are regulated because relationships exist between these features – that we can develop the means to integrate an urban development into the landscape. After all, if we accept that we are not merely building a city within a wetland, but attempting to merge two contradictory systems – i.e. integrating urban development with the processes carried out by the wetland – then it is not enough to simply "do no harm" or to offset that harm by recreating generic wetland conditions carrying out generic wetland processes. Research over the last ten years has shown that this is surely possible[2], but since networked

Facing pages, figs. 2.2 - 2.7: Views looking north along the Athabasca River and Highway 63 north of Bitumount, illustrating a number of landscape conditions.





processes such as wetlands create specific ecological relationships within specific ecological territories (ignore for a moment the fact that those boundaries may be blurred across large territories and timeframes), the next phase of sustainable urban development must move beyond generic reconstruction as a means of mitigating ecological damage, and must begin to develop and implement the means by which urban development can be integrated with specific wetland types and the processes that occur within a specific landscape network. As has been shown by so much contemporary research[3], any attempt that tries to mitigate the affects of urban development by duplicating generic conditions seems to fail in maintaining the processes and patterns that operated within the landscape prior to development.

Every wetland provides its own unique functions, and it is only by understanding that those functions are the result of the interaction of features and relationships that are structural, that strategies can be developed that allow for urban development to integrate into a pre-existing ecological context. What follows, then, describes wetland functions and the relationships that allow them to exist in order to outline this argument. It presents the idea that these features and relationships are structural, and that there exist specific relationships between specific features that allow the wetland to operate.

A quick sidenote before we begin our description of wetland features and functions: as discussed in the Introduction, it is a central theme of contemporary ecological research that landscape processes cannot be mimicked, and that attempts to redesign landscape conditions often fail to achieve the desired ecological ends. This thesis accepts this as true. As a result, the strategies developed here will not be based on the duplication of wetland processes and structure. To the contrary, as will be discussed in Chapter Five these strategies will not simply recreate landscape features in an attempt to remediate generic landscape functions, but will seed processes that allow for the landscape to recreate its own structural relationships and thereby heal itself. In any case, such

Facing page, figs. 2.8 - 2.13:
Landscape features along the Athabasca River. Clockwise from top left: hummocks in the landscape; a meandering stream in the Athabasca Delta; transgression lineaments; glacial till forms washover remnants and braid bars in shallow water; riverbank avulsion revealing a thin layer of topoil and sandy subsurface conditions; transgression lineaments as evidence of a moving littoral.

Wetland Types

BOGS

Bogs are wetlands formed in cool, wet areas where drainage is poor and the soil lacks oxygen. Rain and snowfall supply most of the water to a bog, and thus bogs are low in nutrients. Usually covered by dense, floating mats of sedges, and mosses, they range in colour from pale green to dark red. As the bog ages, dying layers of moss and sedge accumulate into layers of peat.

Bogs are highly acidic, and thus attract low shrubs and trees that are adapted to low nutrient levels and acidic water. Typical species include tamarack and black spruce, and platns such as sundews, pitcher plants, cranberries, and cotton grass.

Typically a bog resembles a forest that is not growing vigorously.

Features/Location:

Peat covered areas or peat filled depressions with a high water table.
Raised hummocks, separated by low, wet interstices.
Greater than 40 cm peat accumulation (peat rich)
Organic soil: soils consisting almost entirely of organic matter

Hydrology:

High water table
Stagnant: no incoming waterflow, no seasonal flooding, poor drainage. Source of water is precipitation only, or seepage from surrounding acidic rock and soil. No contact with external nutrient-carrying water
- Nutrient poor and acidic - pH 3 - 5

Plantlife:

Surface carpet of mosses, mainly sphagnum, predominate, with heath family shrubs, and certain sedge species.
May be treed or open. Trees include Black Spruce (Picea mariana), Labrador Tea, Bog Cranberry, Bog Laurel, Creeping Snowberry, Sundew

FENS

Like bogs, fens are also peatlands, but are distinguished from the former in that they are mainly fed by groundwater. Fens commonly develop on a base of limestone or clay, are often covered by floating mats of vegetation, and may or may not be treed.

Though water does seep through the dense layers of vegetation that often cover the fen, these wetlands are typically innundated -- fens sit at or just slightly above the water table -- and plant decay and the accumulation of peat is inevitable.

Water found within a fen is typically less acidic and more nutrient rich than that found within a bog, but for the most part, fens attract acidic loving vegetation. Although dominant plants are sedges, grasses and mosses, some fens are densely covered by black spruce, tamarack, and shrubs.

Similar in both appearance and plantlife, distinguishing visually between bogs and fens is difficult, and to do so requires a knowledge of water chemistry and source.

Features/Location:

Peat rich, characterized by accumulation of greater than 40 cm.
Soils are high in organic matter, and have a higher mineral content than bog soils
Less acidic. Relatively nutrient rich and minerotrophic.

Hydrology:

High water table
Wetter than bogs, but stagnant. Source of water is predominantly precipitation but some inflowing water (from surrounding slopes, seepage from surrounding rocks or small streams, sometimes flooding).

Plants:

Dominated by sedges, although grasses, herbaceous and shrubby plants, and reeds may be found
Much low to medium height shrub cover and sparse layer of trees.
Tamarack (Larix laricina), White Cedar, Marsh Cinquefoil, Bog Willow, White Beakrush, Bogbean, Slender White Aster

MARSH

A marsh is a type of wetland lying within a depression and surrounded by dry land. Marshes are formed when water moving across a landscape collects within standing pools or disconnected channel networks.

Characterized by the movement and replenishment of water (during annual flooding cycles), marsh soil is highly mineral, and as a result, marshes are dominated by herbaceous plantlife and vegetation.

Though nutrient rich, marshes remain flooded for the majority of the growing season, and plant roots are inundated throughout the year. Thus, emergent plant species are most commonly found within the marsh itself, and stands of trees and shrubs that prosper in mineral rich soil are found in the grassy meadows that often border these sites.

Features/Location:

Wet areas periodically inundated with standing or slow moving water and/or permanently inundated areas.
High mineral content organic soils.
Circumneutral to slightly alkaline and high oxygen saturation.
Attracts waterfowl. Lake Erie and Lake St. Clair marshes are quality habitat for staging. Dabbling duck
for feeding.

Hydrology:

Open water.
Surface water levels may fluctuate seasonally, to expose mud flats.
Ponds, shallow lakes, reaches or impoundments.

Plants:

Characterized by robust emergent species. Floating plants and submergent species also.
Red Osier Dogwood (Cornus stolonifera
Common Cattail, Marsh Spike Rush, Broad-Leaved Arrowhead
Fragrant White Water Lily, Floating-Leaved Pondweed

SWAMPS

Related to bogs and marshes, but uncommon in Alberta, swamps are forested wetlands that are flooded seasonally by standing or slow moving water. Created as water moves slowly through a forested depression, they are are characterized by an abundance of living and dead trees and shrubs. Since the tree canopy can be exceedingly dense, they are sometimes referred to as forested wetlands.

Nutrient and mineral rich as a result of the ongoing replenishment of source waters, both coniferous and deciduous trees are abundant within a swamp. Since flooding occurs seasonally, and water flows across the site for at least a part of the year, peat accumulation is minimal within a swamp.

Features/Location:

Wooded wetland with 25% cover or more of trees or tall shrubs.
Water is circumneutral to moderately acid.
Little deficiency in oxygen or mineral nutrients.
Attracts waterfowl. Dabbling ducks breeding habitat, feeding, resting and staging for others.

Hydrology:

Standing to gently flowing waters occur seasonally or persist for long periods on the surface.
Characteristically flooded in spring with dry pools later in the season.

Plantslife:

Coniferous trees, tall shrubs, herbs and mosses,
Shrub swamp: Willow, Dogwood, Alder
Hardwood forest swamp: Silver Maple, Elm, Black Ash (Fraxinus nigra), Yellow Birc
Conifer swamp: White Cedar, Tamarack, Black Spruce
Jack-in-the-Pulpits, Trillium, Lady Fern, Sensitive Fern

a leap – from simple landscape manipulation to the integration of urban development into a complex network of ecological processes – is only possible if one first understands the processes that are taking place within the site context, and if we understand that these take place as a result of complex relationships that are both fragile and impossible to duplicate. This Chapter, then, will outline those features, and makes it clear that those relationships do in fact exist, and can be considered structural, organizing features.

Historically, few attempts have been made to describe the complex character that defines wetland structure[4], and thus, wetlands have been typically defined in the most generic of terms. Contemporary research, however, reveals that the term "wetland" encompasses a broad array of landscape types, each of them unique in their complexity, character, and the functions that they carry out.

In the most general sense, a wetland is defined as any landscape containing an excess of hydrology that prevents the complete decay of biomass[5]; typically this excess is in the range of ninety-five percent water by weight, a fact belied by a wetland's virtually solid appearance, and their ability (however tentative) to support mass.

Wetlands are categorized into four structurally and hydrologically distinct groups[6]: bog, fen, marsh, and swamp. Differences between the four types are distinguished by the location of the groundwater source, the rate of water movement within the wetland body, the degree to which water is recycled within the body; and the rate at which this occurs. Though subtle, the differences between these generative conditions create unique characteristics[7] that have a direct bearing on this thesis: in terms of potential architectural development, the characteristics that derive from these differences allude to the presence or absence of certain subsurface structural (hydrological, morphological) conditions that could

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Facing page, fig. 2.14:
A chart describing wetland types.

have a direct effect on construction techniques deployed at the site (and whether construction could occur in the first place). In terms of ecological integration, the differences that derive from these conditions create very specific types of landscape features, each characterized by a specific morphology, unique biological, structural, and ecological relationships, and the presence of specific plant and animal life. Each of these features bears a direct relationship on the structure of ecological processes occurring at the site, and thus, identifying their differences will be key in creating a solution that allows development to integrate with those processes.

Since the purpose of this thesis is to develop a strategy for integrating urban development into a wetland landscape in which sensitive ecological processes are occurring, then we must understand the processes occurring on the site, and the means by which those processes function. What follows is a brief list of ecologically significant benefits provided by wetlands.

Wetlands provide habitat to many plant and animal species[8], play a role in increasing plant and animal population diversity, and have a direct effect on species productive capacity[9]. Alberta's boreal wetlands sustain over six-hundred species of wildlife, including numerous endangered species. They provide food, shelter, nesting grounds, and hunting grounds to numerous species of birds (both local species and those that from as far away as Florida and Inuvik), ducks and geese, one hundred and fifty species of mammals, scores of fish species, amphibians, and a great diversity of plant species and symbiotic bacteria and soil microfauna.

Wetlands recharge water supplies and replenish aquifers, and thus, play a critical role in influencing the character and quality of river, lake and stream water[10]. As well, wetland depressions play an important role in recharging groundwater, storing water surge, and retaining snowmelt,

Facing page, figs. 2.15 - 2.16: Top: a swamp adjacent to the Athabasca River. Bottom: a bog overtaking a woodlot along the Athabasca River.

spring runoff, and groundwater within local aquifers[11]. Thus, they play a significant role in providing water for irrigation and replenishing water supplies for human use[12]. Estimates suggest that for every cubic metre of lost wetland, associated groundwater loss is fifty percent of that volume[13].

Wetlands not only store water, but they filter it and make it potable and suitable for agricultural use. The boreal wetlands act as a sponge that absorbs and processes pollutants[14] present in groundwater (in the form of sediments), and in airborne pollutants present in precipitation[15]. If the rainforests of the world have been described as the world's lungs, then the boreal wetlands, acting as they do as a global filter, can be characterized as the planet's kidneys processing waste from rainwater and recycling clean water back into the global system through evapotranspiration[16].

Wetlands also play a role in maintaining air quality, and links have been found that suggest that air quality is directly affected by groundwater quality, and that groundwater pollution is directly related (both as cause and effect) to air pollution[17].

Wetlands control run-off, erosion on a territorial scale, and widespread flooding. Because they act like a sponge, wetlands control and mitigate run-off rates and snow-melt, control ground water movement, control rates and patterns of flooding, and during flood events themselves, absorb water and mitigate flood consequences. Groundwater pooling also reduces rates of soil movement and erosion as a result of rains, run-off, or floods. In other words, wetlands play a significant role in maintaining those hydrological patterns to which we have adapted our own agricultural and settlement patterns[18]. In fact, it could be said that functions related to wetland processes, water storage, and erosion control determine where agriculture can occur and allow it to take place.

Wetlands act as carbon sinks, absorbing and retaining as much as thirty-five percent of the world's terrestrial carbon, a number equal to twice the amount retained in the forest biomass of the world. Alberta's Boreal forest stores eleven percent – or one-third – of the world's terrestrial carbon, and half of that number is stored in wetland biomass and peat. This number represents an excess of one hundred and eighty-six billion of tonnes of stored carbon, an amount equal to twenty-seven years worth of the emissions created by the combustion of fossil fuels[19]. The destruction of a wetland, then, represents not just the loss of a carbon sponge, but the possibility of a sudden and massive emission of carbon into the atmosphere (what some ecologists refer to as the global carbon H-bomb) [20].

Boreal wetlands play a direct role in maintaining global precipitation patterns, and controlling air mass movement across North America[21]. Wetlands not only store water, but they do so at a constant temperature, and these ground temperatures play a vital role in regulating air mass movement. In North America, the boreal wetland plays a significant role in maintaining Jet Stream patterns, and thus, any change in groundwater temperatures (some scientists cite as little as 4 degrees) would modify not only its frequency, duration and timing, but also the amount of precipitation that it brings[22].

Moreover, by maintaining groundwater temperatures, wetlands operate like air conditioners and play a direct role in mitigating the effects of global warming.

Finally, wetland landscapes play a significant role in allowing for species growth and rich genetic diversity by acting as specialized ecological landscapes referred to as source/sink environments[23]. According to the ecological theory that produced the term, organisms of the same species may, in order to survive a landscape prone to dynamic fluctuations (flooding, or turbulent landscape change, river-bank migration, or avulsion as described in Chapter One) form several distinct population pockets, each population independent from the other, and each with a finite life span. Though neither population can guarantee the long-term survival of a given species, a small amount of migration between each group (between a high-quality "source" landscape, and a lower quality "sink" landscape) can ensure that each population's life

Following pages, figs. 2.17 - 2.18: Transgression lineaments and braid bars at different locations along the Athabasca River. These features are both caused by, and lead to, meandering river patterns. A detail (fig.2.18) reveals the extent of landscape deformation caused by these features.

span remains stable and that the population as a whole thrives over the long term. Though impossible to identify as either a source or a sink, wetland landscapes almost always function in one of these regards, and the survival of many wetland species is inherent to the maintenance of a source-sink dynamic. Thus, the wetland ensures the viability of species longevity by providing more than just habitat, and operating as one half of this significant ecological process.

In short, wetlands provide plant and animal species with habitat, play a role in increasing plant and animal population diversity, have a direct effect on species productive capacity, and provide a source/sink environment that ensures the longevity of wetland species and allows for genetic diversity. They recharge water supplies and replenish aquifers. They filter water and make it available for agricultural use. They control flooding and erosion, mitigate the effects of global warming by controlling air temperatures, act as carbon sinks, and play a direct role in establishing and maintaining precipitation patterns that allow for agriculture, and that govern much of the seasonal behaviour to which we have become accustomed. Not only do they maintain local ecological relationships, they also affect the function of global ecosystem processes. As such, they play a role in regulating patterns and processes that have a larger impact on our lives (as flooding does, for example), and initiate conditions that govern broadly scaled human activities (in this case agriculture, settlement as a result of industrial activity, and industrial production related to the oil industry), ultimately influencing the social and economic patterns that are governed by these activities[24].

Before we can propose interventions that offset the damage inflicted on the processes described above, we must determine both how those processes

Facing pages, figs. 2.19 - 2.21:
Subsurface water channels and pockets created by glacial activity create weak spots in bedrock or deposition till. Impossible to forecast, sinkholes appear suddenly and with devastating effect. In the image at top-right the landscape has begun to reclaim a sinkhole.
Following pages, figs. 2.22 - 2.23:
(left) A mat of plantlife and trees growing on shallow bars and floating on the Athabasca River camouflages the distinction between land and water in this photo. For scale, compare the same photo to the one at right. In this one, the northern bank edge has been scaled to reveal the presence of trees along the bank.
(right) In this scaled image of the one at left, what seems at first to be a thin layer of low plantlife is revealed to be a dense layer of trees growing along the Athabasca River. The scale and density of floating mats of bog plantlife effectively obscure the presence of both firm ground and super-saturated soil.

work, and how they define wetland structure (since the relationships that define these features will have a direct influence on how the site will be developed, and on the shape and nature of the strategy designed to integrate with them).

A survey of contemporary wetland research reveals that wetlands are not simply static geological phenomenon, but result from a complex interaction of ecological forces (geological, hydrological, morphological, and biological) that coalesce to form an incredibly resilient but ultimately very delicate entity[25]. Their structure is both physical (defined by the physical properties of landscape forms and the interaction of forces on the site), but also biological – defined as it is by an interplay of species activity at key locations on the site – and thus dynamic. They are both two-dimensional (which is to say, the result of linear causal relationships) and three-dimensional (defined across timeframes, and resulting from the interaction of dynamic processes), and are defined by complex[26] structural networks that are interdependent and mutually influencing[27]. They are, in fact, living systems linked according to non-linear ahierarchical relationships, and as such cannot be described structurally only in terms of static physical and temporal features but must be defined in terms of the temporal and physical relationships that exist between their component parts, and not only at the immediate scale, but across scales[28].

So, for example, unlike a static system in which structural features define static conditions, wetlands are not defined simply by the presence of key physical relationships. Rather, static relationships (for example, between the height of the riverbank and the rate of seasonal flooding) mediate relationships between other physical features (for example, the existence of a breakwater on the edge of a riverbank) and between the relationships that exist within the ecological framework of which that wetland is a part, and between other processes in surrounding ecological frameworks.

As Edmundo Drago describes: "water-level fluctuation, topography, and spatial location create a heterogeneous pattern of connectivity…

Flood events connect islands with the river and support the exchange of matter and organisms between lotic and lentic habitats, a primary factor for ecosystem dynamics and functioning. Connectivity influences, for example, diversity and productivity across different hierarchical scales."[29] Structural relationships, as we will see below, are dynamic and exist between both static and dynamic forces, and between static features and both dynamic events and relationships between events and phenomena.. Ultimately this means that our own intervention must either be dynamic and capable of change, or able to evolve to accommodate this dynamism.

Since wetland structure is defined by the relationships that exist between a number of context-specific landscape features, I will now describe some of these[30]. The list is not exhaustive but is complete enough to highlight the linear, circular, and ahieararchical nature of the structural relationships that exist at the site[31].

Wetland generation is a direct result of the presence of a drawdown curve, a conceptual feature that describes a riverbank's ability to withstand a variety of hydrological pressures and support both the adjacent landscape and the flow of water within the river itself, and to draw water from the river into the adjacent landscape, and out of the adjacent wetland and back to the river (thus defining the degree of wetland saturation).

Drawdown curves function in direct relation to riverbank heights, a feature that affects the rate of direct water exchange between the landscape and the river, the nature of and relative ecological richness of the adjacent riparian zone, the ability of the wetland to draw water into itself, the wetland's ability to protect itself against degenerative external pressure such as wave action, water pressure, and avulsion, the nature and relative ecological richness of subsurface and surficial relationships between plants and animals at the water's edge, and the relative richness

of other structural features (such as parafluvial ponds).

Riverbank height, strength and viability are directly affected by the degree of bank compaction, and whether or not the bank iss planted or bare. Furthermore, it is affected by subaerial and subaqueous weakening as a result of fluvial stress, by weathering, by the physcial forces that define potential entrainment capabilities within the river, and by sediment flow and deposition. Sediment flow and deposition are themselves affected by sediment grain-size and hydrological forces (including wave action), and these in turn are affected by bank height. Like an episode of Seinfeld, the relationship is a circle.

Moreover, a complex interplay of biological relationships exist at the water's edge – what ecologists refer to as trophic linkages across ecotones – in the hyporheic zone, and these affect bank edge conditions (such as strength), which in turn affect bank structure. Each of these also affects the potential for biodiversity within adjacent sites. And this, in turn, is affected by nutrient flow within groundwater and within the river.

Bank structure is further affected by bank pressure, bank stability, and both soil and plant retention. And each of these further affects the nature and richness of the riparian zone. Simultaneously, each of these conditions are in a constant state of rearrangement as a result of fluvial processes, seasonal changes, and climate extremes.

Obviously the processes and features that define marsh structure are both highly interconnected and complex ("non-linear" as opposed to "complicated"), given that this structure is defined not by static connections between structural features, but by relationships, and given that those relationships are undergoing constant shifting as a result of the mutual influence that each feature and process bears upon the other, and that they are doing so across three dimensions (laterally, vertically, and, since the River moves upstream, longitudinally[32]) while simultaneously being redefined under the influence of stronger and more unruly forces. Wetlands are, in other words, highly sensitive and incredibly fragile,

Facing page, fig. 2.24:
Avulsion on the eastern bank of the Athabasca River, just north of the site.

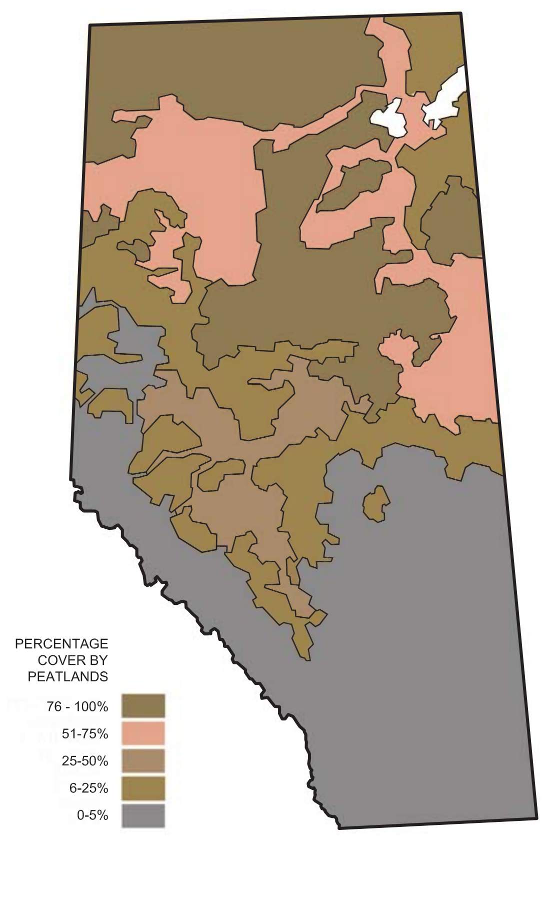
interconnected in a multitude of fashions across several phenomenological and physical scales, characterized by a multidimensional character that can operate in ways that contradict both logic and physics[33], and ultimately, impossible to duplicate.

In Chapter Two we provided a general understanding of wetland function, wetland composition, and the systemic conditions that must be maintained in order for wetlands to continue to function. We described the role that wetlands play within the local ecology, the role that they play within broader ecological systems and the complex relationships that exist between the wetland and a number of local systems. As well, we discussed the structural features responsible for creating and maintaining the morphology and function of the wetland, and the systemic conditions that must be maintained in order for wetlands to continue to function. We did so because we cannot develop a strategy for integrating urban development into an ecosystem without first understanding the relationships that govern the complex processes that this will interupt.

Chapter Two conceptualizes as "structural" any feature and process that ensures the operation of the wetland system. This underscores the fact that wetland processes are contingent (upon a series of relationships that are themselves contingent and tenuous), and that these processes cannot be easily interrupted without damaging the function of the whole. We cannot simply introduce new construction without expecting to damage pre-existing processes, and given the complexity of their structural interconnectedness, we cannot attempt to simply rebuild a wetland as per current remediation techniques without expecting that attempt to fail at recreating these precise relationships[34].

Simultaneously, this conceptualization provides the building blocks that allow us to develop the 8-step strategy presented in Chapter Five. Of course, before we can present a strategy that proposes methods

Facing page, fig. 2.25:
A view of a riverbank south of the site reveals glacial deposits ranging in size from till to large rock formations.


PERCENTAGE
COVER BY
PEATLANDS
76 - 100%
51-75%
25-50%
6-25%
0-5%

for offsetting the damage caused by urban development, we must first describe the damage caused by this development.

Facing page, fig. 2.25:
Albertan wetland coverage

Footnotes

[1] Even though wetland ecologists do not describe wetlands in these terms, a survey of contemporary wetland research makes it absolutely apparent that the landscape's ability to carry out ecological tasks is a direct result of the relationships that exist between local physical features and landscape phenomena.

[2] See all of those projects completed in the past decade that have had wetland remediation as their central theme: the Sydney Olympic Site Development, New York City's Fresh Kills remediation, Toronto's western portlands redevelopment proposals; et al. See also the many (upwards of twenty) examples provided by Izembart and Le Boude in their book "Waterscapes".

[3] Referenced in the Introduction above.

[4] Bergkamp and Orlando, 1999.

[5] Charman, 2002.

[6] These groups are further subdivided into a smaller subset of more complicated types. Distinguishing between these types is not relevant to the current discussion. In Chapter Four, subset specific structural features will be described, but not attributed to specific sub-type.

[7] National Wetlands Working Group, 1998.

[8] Locky, Davies & Warner, 2005.

[9] Christer and Dynesius 2006; Kershaw 2001.

[10] Karaus 2005; Ayres and Weaver 1998; Palmer 1985.

[11] Bruneau and Toth 2006, Jarvena 2006, Ohlewiler 2004.

[12] Green, Macdonald, Melville & Waite 2006.

[13] Cutlac and Weber, 2006.

[14] Gold, Groffman, Addy, Keloogg & Adam, 2000.

[15] National Research Council,2001.

[16] North Carolina State University Water Quality Group, 2003.

[17] Apps, 1993.

[18] Koshida, Stratton, and Wheaton, 2006.

[19] Tarnocai, 2006.

[20] Jarvenpa and Brumbach, 2003.

[21] Charman, 2002.

[22] Moldan, 1994.

[23] Hanski, 1999; Dias, 1996; Howe, Davis & Mosca 1991; Titler, Fahrig & Villard, 2006.

[24] See the case of the Pacific Coast fishery described in the following chapter.

[25] Just how delicate? Consider Collins' work (2001) that suggests, for example, that "bank elevation matters a lot… A 2cm rise in high tide (or a 2cm drop in marsh elevation) causes a 15% increase in hours of inundation" and "radically alters" the communities living on that wetland. Couple this with Schwimmer and Pizzuto's (2000) work in which it is proposed that a relatively minor fifty centimetre change in bank elevation on a wetland adjoining a river can irreversibly alter the function of that wetland. Both of these cases demonstrate the even minimal tampering can cause ecological damage, and that a delicate (and ultimately surprising) balance exists between even the most minimal hydrological and morphological forces that define site conditions.

Consider as well this comment from Schindler (1998): "Because they contain such small numbers of species, boreal ecosystems have been largely ignored by those concerned with declining biodiversity. As I have argued earlier… this makes no sense from an ecosystem standpoint… The disappearance of only a few species has been shown to … to compromise vital community and ecosystem functions… and impair the proper functioning of food chains and biogeochemical functions in boreal lake systems (Schindler et al. 1985a, 1991, Rudd et al. 1988, Schindler 1988b, 1990b)." Italics mine.

[26] According to Allen and Hoekstra (1997), a complex community is one in which a large number of elements or phenomena defined at a lower level of organization all interact in "multifarious" ways to produce upper level "community" effects: "Complexity [refers to the linking of] small entities from a low level of organization with large entities from higher levels."

[27] In fact, the description of wetland functions discussed above highlights the very fact that no wetland feature is an isolated entity, and that all of its functions are dependant on the operation of activities occurring at other scales. Wetlands and their processes are mutually influencing networks of processes nested within each other to create large ecological frameworks.

[28] Cairns, Niederlehner & Smith, 1995

[29] Drago, 1989.

[30] Fuller descriptions of these and other significant features are included in the Glossary. Though

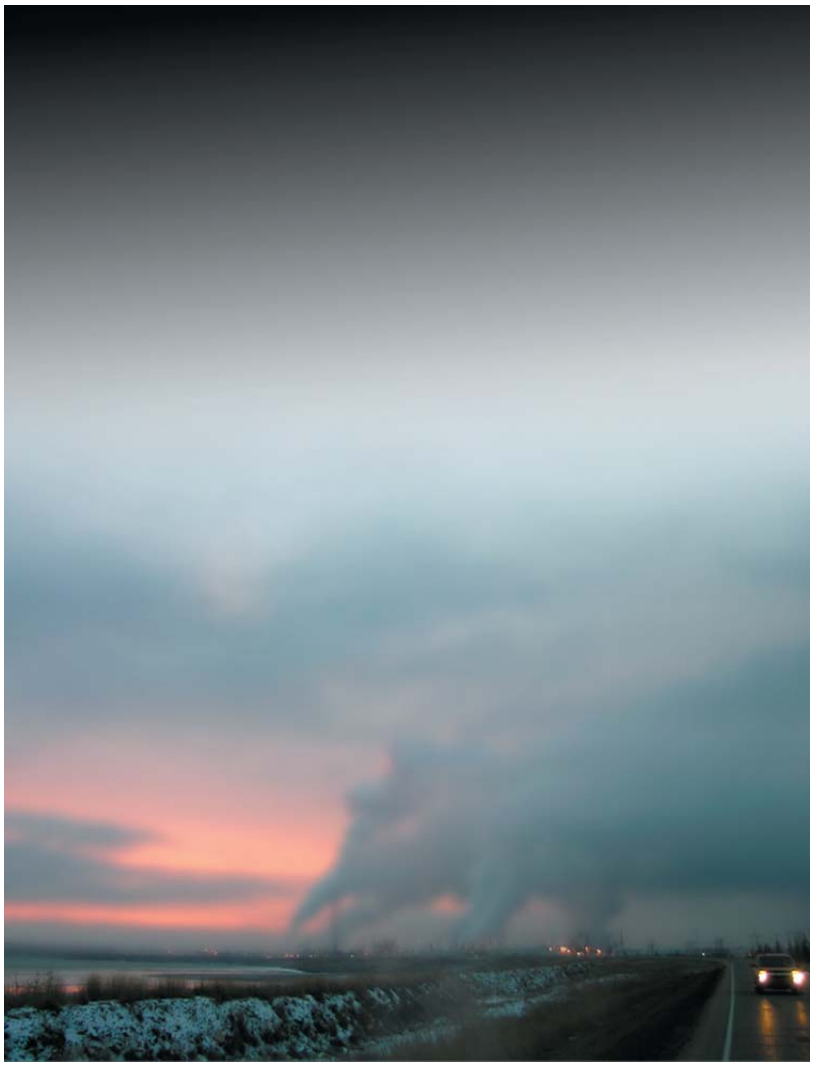
not described here, the final intervention relies upon a working knowledge of riparian zones, hyporheic zones, stream gradients, braid bars, moving littorals, transgression lineaments, and parafluvial ponds, and so the reader might familiarize himself with these before reading Chapter Five.

[31] What follows is derived from a reading of many of the authors listed in the bibliography. Individual citations are not provided since the description of linked processes is currently accepted as typical and not attributable to any one source. See, for example: Westerberg and Wennergren, 2007; Becker, Ahang, Cihlar, Ileka & MacGregor, 2006; Sorooshian, 2006; Polster, 2002; Rowntree and Dollar 1999; Gatto. 1995; Cairns, Niederlehner & Smith, 1995; Gray and MacDonald 1989; and, Nieswand, Chavooshian, Hordon, Shelton, Blarr, Brodeur & Reed, 1989.

[32] Ward, 1989.

[33] See Schwimmer and Pizzuto (2000) once again. Here they show that when shoreline erosion occurs, the marsh – contrary to expectations – does not "drown", but actually flourishes. The force that should erode the marsh is balanced by other forces within the hydrological network to create a response that contradicts expectations.

[34] Take habitat complexity as an example: Tockner's work (2004) shows us that habitat complexity is directly related to complex biodiversity. Thus, simplifying that biodiversity ultimately leads to interventions of diminished complexity. Or Colella's work (1988) that shows that similar strategies employed in different locations can have divergent results. Or Kuroiwa's work (2004) on bridging and bank creation that discusses the failure rate of banks under different conditions. Or Trimble's work (1997) that concludes that small changes to riverbank structure can create horribly disproportionate effects; and, that landscape interventions often create greater ecological damage than the damage that would have occurred if the mitigating intervention had not been carried out. Both Chilcote (2003) (discussing means of maintaining complex trophic linkages at a riverbank edge) and Christer Christer, Nilsson and Dynesius (2006) (describing porous boundaries between scales and events within processes) come to similar conclusions.



chapter three

Consequences of Wetland Development

If Chapter Two described the ecological functions carried out by wetlands, the relationships that allow those processes to occur, and the structural components that organize and govern their function, Chapter Three outlines the damage that urban development inflicts on these processes and structural features. It begins by describing difficulties associated with wetland construction and the typical methods used to overcome these. It then outlines the scope of wetland damage as a result of urban development and shows that such damage is never restricted to the site alone, but is magnified across scales to affect all of those systems of which the local landscape is a part.

Given the hydrological and geological peculiarities of wetland sites, wetlands present a number of physical obstacles to construction. The landscape adjacent to the Athabasca River north of Fort McMurray is characterized by an incredibly high groundwater content, by an absence of structurally supporting features (bedrock is difficult to find and its depth its depth varies radically, located anywhere from five to two hundred metres below the surface), by shifting plains of non-structural glacial till[1], and by expanses of subsurface water that are hidden by mats floating mats of decomposing peat. It is prone to avulsion, landslides, and violent rearrangement as a result of fluvial processes.

Subsurface channels undercut much of the landscape creating

structural weak-spots that cause sinkholes to appear suddenly. The movement of this subsurface water displaces large chunks of terrain to create chunky hills in the landscape (hummocks), and along its riverbanks the meandering Athabasca River creates convoluted folds of earth that migrate into the landscape like dunes[2], creating heaving rippled surfaces in the non-structural till.

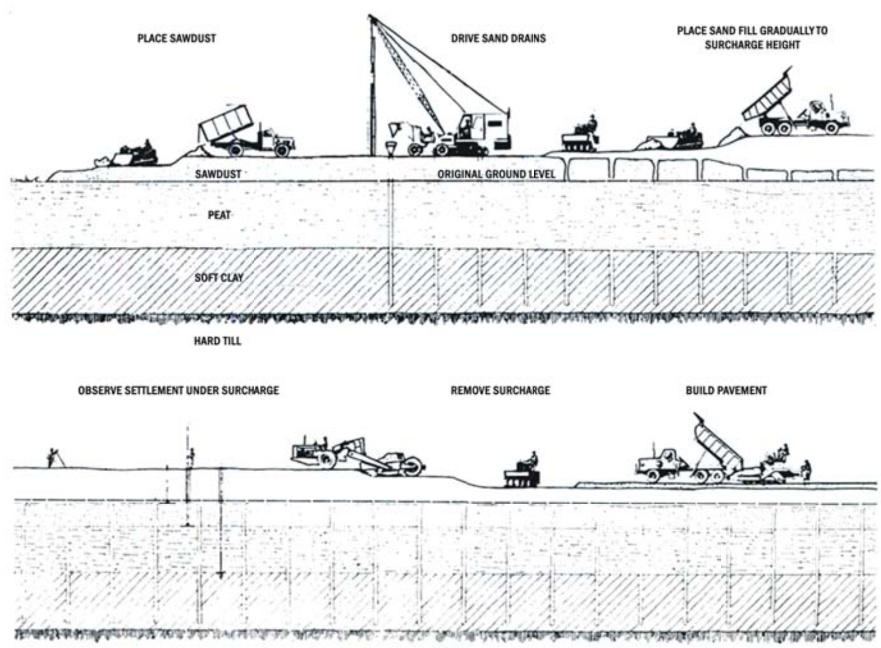
The landscape's high water content creates difficulties in relation to drainage and differential settlement[3], and subsurface channels ensure that ice and underground water undermine attempts to drive piles and/or lay foundations[4]. The site is prone to seasonal flooding, and though it rests above the high-water line of the Athabasca River, it is never dry, never less than ninety-five percent saturated. Lateral forces as a result of a constantly shifting groundplane place further pressure on building structure, and undermine building stability[5].

Marshy, oversaturated, bog-like landscapes are not particular to northern Alberta, nor even to North America, and since their presence is global, numerous cultures have evolved techniques that allow for construction on a wetland landscape[6]. That said, the four techniques detailed below are those that are typically used when building on wetlands in North America[7].

Current techniques for building in wetlands are outlined by Ivan MacFarlane in *The Muskeg Engineering Handbook*. MacFarlane's book confirms that the typical approach to building within wetland regions is one which pays little respect to the processes occurring in the landscape. In each of the methods he describes the wetland is dredged, the surficial biomass is stripped away, the resulting hole is backfilled, and construction takes place on top of an artificial mat that is constructed to float within (on top of) the landscape.

The typical approach to building large scale developments within

Facing page, fig. 3.2:
A wetland graded for suburban development.


PLACE SAWDUST
DRIVE SAND DRAINS
PLACE SAND FILL GRADUALLY TO SURCHARGE HEIGHT
SAWDUST
ORIGINAL GROUND LEVEL
PEAT
SOFT CLAY
HARD TILL
OBSERVE SETTLEMENT UNDER SURCHARGE
REMOVE SURCHARGE
BUILD PAVEMENT

wetlands is referred to as the "Complete Removal and Backfilling Method". In this method surficial overgrowth is simply dredged and stripped away revealing clay or soil beneath. This area is then back-filled with gravel and construction is carried out on top of this layer. Retaining walls hold back the encircling peat at the limits of the intervention.

The rafting (or scabbing) method is also common, and differs from the first approach only in that the peat is not removed before a concrete or granular-fill slab is simply poured on top of the biomass. Construction takes place on top of this new datum. The method is a shortsighted one (even if we choose to ignore the attitude displayed toward the landscape): because the site is not dredged, the oversaturated groundcover creates an uneven surface and differential settlement is quite common for even the smallest of buildings.

A third method, referred to as "site preloading", has been developed to deal with the differential settlement issues that both method one and two are prone to. In this method, a surcharge is applied to the site prior to construction to create a compacted level bed upon which to build. This limits the extent of settlement that can occur after construction is complete. Unfortunately, it is often difficult to preload a site that is intended to be developed with large scale buildings since it is difficult to apply a weight that is equal to or greater than the weight of the finished construction.

For small buildings, a method referred to as "friction piling" is used. In this case piles are sunk into the ground, the building is erected on top of these, and loads are simply transferred through friction from the piles and into the surrounding landscape.

It goes without saying that construction within a wetland will have immediate and destructive effects on the landscapes characteristic

Facing page, fig. 3.3:
An image from Ivan MacFarlane's book illustrates the typical method for removing overgrowth and building on a wetland.

features[8]. And whereas this is true, if we are to develop methods for sustainably developing an untouched landscape, we should quantify the type and scale of this damage, such that we can present construction strategies that will lessen (or contain) the impact of this development (locally) and attempt to eliminate the damage that occurs at the broader territorial and system scales.

Urban development of wetland landscapes inflicts immediate damage on local features. It interrupts river processes, either physically as a result of damming (when near-river construction erodes riverbanks and releases larger-than-normal sediment flows into adjacent rivers)[9], or as a result of the introduction of new sources of pollution (such as urban runoff, automobile runoff, and industrial runoff)[10] into affected landscapes. Such physical damage has immediate effects on nutrient flow within a river[11], hydrological forces and processes within a river[12], the function of landscape processes that are linked to those hydrological processes[13], local flooding patterns[14], riverbank stability[15], and pond and channel formation in the structural zones immediately adjacent to the river[16]. Given the degree to which these features are interconnected, and the direct role they play in maintaining wetland structure and long-term viability, it is clear that the damage inflicted on these features and processes has an immediate effect on the viability and longevity of the associated marsh, and on that marsh's ability to carry out ecological functions.

At a larger scale, urban development of a wetland site not only inflicts damage on the structural features that define that site's viability, but creates changes in the way that related marsh systems operate. As we said in regards to local damages above, if we are to develop methods for sustainably developing wetland sites, we must come to terms with the systemic changes that such development would cause, such that the strategies we develop below will mitigate the damage that occurs at broader system scales.

By damaging both physical and biological relationships within a wetland site, urban development creates systemic changes within the wetland and modifies the manner in which that wetland functions, thereby eradicating or modifying the beneficial ecological effects brought about by those wetland processes. Because of the changes that it initiates, urban development has an immediate effect on a wetland system's ability to filter water. Thus, urban development of this site would immediately impact the health and quality of the Alberta aquifer[17].

Since a wetland acts like a filter that purifies the water that moves through it (either as groundwater, or within subsurface channels or the water table), incapacitating that ability not only lessens the landscape's ability to carry out this function, but also creates an incredibly efficient mechanism for distributing new pollutants throughout the landscape[18].

Moreover, urban development has immediate effects on local wildlife populations. By modifying the landscape's absorptive properties[19], leveling the landscape (and accelerating rates of run-off flow into rivers adjacent to the cleared lands[20]), and simultaneously increasing the flow of pollution through local groundwater[21], urban development modifies rates of water flow in the watershed, increases pollution within the river[22], and renders water less hospitable to fish[23]. Additionally, riverbed plantlife disappears and fish lose habitat and food.

The water cycle is also affected. The destruction of wetland landscapes reduces the potential for groundwater storage, and as a result, aquifers are not replenished at a viable rate[24]. Ironically, the potential for massive territorial flooding is increased since wetland encroachment, landscape flattening, and wetland dredging reduces the landscape's ability to retain water[25], resulting in swifter and more voluminous surface transport[26].

Wetlands exist as a result of complex networked relationships occurring between hydrological, geological, and morphological features, and between those features and hydrological, geological, and biological


ATCO
WIDE LOAD


PTI
GROUP INC
WELCOME
ATHABASCA
BEAVER RIVER

processes and events. Simultaneously, they operate as functional and structural components with larger networked relationships. Thus, local damage is not only confined to the physical boundaries of the site, but is transferred across scales and has far-reaching effects[27]. Most notably, since the relationship between groundwater temperature and the air above a marshy landscape drives air mass movement, fluctuations in groundwater temperatures (as a result of wetland destruction or as a result of changes in temperatures of runoff entering into the landscape), creates fluctuations in air mass circulation, and disrupts climatic patterns[28].

Such a shift directly impacts weather patterns, global heating and cooling cycles, and precipitation patterns. A change in air mass movement and in air temperatures and the introduction of a variable relationship between air temperatures and ground temperatures causes a change in precipitation cycles (their timing), rates of precipitation, and locations where rain is apt to fall[29]. At one extreme, such changes lead to a reduction in rainfall volume which creates an increase in frost free days and a decrease in cold days[30]. This has a direct impact on agricultural patterns, and can lead to reductions in production, shortages, and economic downturns in those economies based upon it[31]. At the other extreme, increased run-off in areas with positive changes in precipitation volume, increased snowmelt, and decreased ability by the landscape to retain water creates conditions conducive to massive flooding.

These changes in weather patterns, groundwater temperatures, and precipitation cycles do, in fact, have a direct economic impact, both locally and further afield[32]. By studying land use change in response to water restrictions as a result of climate change, Weber and Cutlac (2006) have attached a dollar value to the effects that water loss is causing within the Albertan economy. Subsequently they determined that seven percent of the profits generated by agriculture in Alberta every year are currently being used to offset the negative effects of climate change brought about solely by the effect that wetland change is having on local water supply

Facing page, figs. 3.4 - 3.7:
Typical appraches to wetland construction. At top right, a prefab housing unit built on a trailer module. In the remaining three images, multi-unit housing derived from modules similar to those in fig.3.4 is shown in use at Syncrude, north of Fort McMurray.

and precipitation.

Having come to terms with wetland processes and structure, and the nature of the ecological damage that urban development inflicts upon both of these[33], we return now to a consideration of the site itself to describe both characteristic site-specific conditions as well as those that will limit, define, organize, influence and determine the nature of the architectural intervention that will be proposed in Chapter Five.

Any intervention will, of course, choose the degree to which it allows the landscape to influence it, the degree to which the context enters into or is shut out of the intervention, and the following chapter presents the parameters – technical, phenomenological, ecological – that frame that discussion for this project (and here I am not speaking to architects, nor students of architecture for whom a discussion justifying the need for, and explaining the relevance of, a site analysis is redundant. I am, however, addressing a more general reader who may not fully understand the extent to which site conditions influence final design). And of course, I am alluding to the much broader phenomenological discussion around which much twentieth century architectural theory has revolved, and which is framed by these two quotes, one by Corbusier (a canonical mid-twentieth century modernist architect) and one by Ignasi de Sola-Morales (a critic from the latter half of the century):

> Corbusier: "A city? It is a confiscation of nature by man. It is an act committed against nature by man."
>
> de Sola Morales: "The uncertainty with which modern architecture broached the question of the formal definition of the object was met, during the crisis of the fifties, with the pantheistic response of the dissolution of the object in the landscape."

Two opposing views that define the extreme positions vis-à-vis the question of whether or not an intervention blends with, is influenced by, or pushes away the local landscape.

All of which to say: before an architect builds within a landscape he or she makes certain decisions that reflect the degree to which conditions within that landscape will influence design. In Chapter Four we present those conditions in a format referred to by architects as a site analysis. The purpose of this analysis is to describe site-specific features that might affect the techniques used to develop that landscape, and to orient the designer within the landscape. The site analysis is not merely a description: it is a snapshot that describes both the physical and the phenomenological character of a landscape. It is both strictly functional and interpretative.

Following page, fig. 3.7 - 3.8:
Variations on a prefab theme. At top, a multi-unit prefab trailer is converted for use as single family home. At bottom, a homeowner gets creative.

Footnotes

[1] MacDonald, Beilman, Kremenetski, Sheng, Smith & Velichko 2006.

[2] Nanson & Hickin 1986 .

[3] In the first case, the persistence of moisture and the lack of drainage opportunities magnify the potential for moisture to wick into building cavities, leading to the growth of mold and possible structural failure as a result of moisture-induced decomposition. In the second case, the movement of water in underground channels and the process of repeated freezing and thawing of subsurface water pockets undermine a site's structural properties, and may lead to eventual

groundplane collapse and/or the slow subsistence of the building into the earth. In either case, differential settlement – whether slight or extreme – can cause havoc to a building's structure..

[4] Francis, 1984.

[5] Strub, 1996.

[6] Tobey, 1973.

[7] Though they are alluded to in Chapters Five and the Conclusion below, the terpen, grachtenstad, and geestgrond (i.e."berming"; see the glossary) techniques successfully utilized by the Dutch to settle similar flooded landscapes are not described here. Variations on those forms will appear in the final Chapter, but at this point, only typical North American construction techniques are described (mainly to show that these techniques pay little attention to processes occurring within the landscape, and have little respect for protecting those processes), but also because those techniques do not fully address the totality of ecological issues related to attempts to protect the landscape from urban development.

[8] Government of Alberta, 2002, 2; Environmental Protection Agency, 2005;

[9] Urban and Rhoads, 2003.

[10] Woynillowicz, 2003.

[11] Ibid.

[12] Schindler, 1998.

[13] Chilcote and Stanford, 2003.

[14] Kowalczyk and Hicks 2003.

[15] Collella, 1988.

[16] Fischer, Martin and Fischenich, 2000.

[17] Becker, Ahang, Cihlar, Ileka, and MacGregor, 2006.

[18] May and Horner, 2000.

[19] Pietroniro, Toth, and Toyra, 2006.

[20] Murgatroyd and Ternan, 1983.

[21] Ibid.

[22] Ibid.

[23] Nieswand, Chavooshian, Hordon, Shelton, Blarr, Brodeur, and Reed, 1989.

[24] In Canada the effects are already being felt. If water availability is measured as the amount of water renewed within a system every year, then Canada renews one hundred percent less water annually than does Brazil, just slightly more than in the US and in China, and fifty percent less than in the Soviet Union. A number of climate models already project that minimum flows within Canadian watersheds will continue to decline another seven to ten percent over the coming four decades. Such a change is bound to affect agricultural patterns as well as land-use patterns (O'Connor (2008)).

[25] Environmental Protection Agency, 2005.

[26] Ibid.

[27] Cairns, Niederlehner and Smith, 1995

[28] United Nations Climate Conference, 2009.

[29] Ibid.

[30] Alberta Environment, Fisheries And Oceans Canada, 2007.

[31] Koshida, Stratton, and Wheaton, 2006.

[32] A unique and well-documented aspect of changes in groundwater temperatures in the Albertan Boreal wetland has been to create dramatic and direct changes on the economies of the Pacific Coast fisheries. As wetlands have disappeared in northern Alberta, and groundwater temperatures have increased, researchers have seen a decrease in abundance in British Columbia fisheries. The explanations posit two possible reasons: on the one hand, a change in precipitation patterns over Alberta may have lead to changes in precipitation patterns (and snow-melt patterns) in British Columbia. A resulting drop in groundwater temperatures (as lake and river temperatures fell in response as increased rainfall and snow-melt) may have affected temperatures in streams leading to the west coast, and may have confused (or scared off) salmon and other fish that swim upriver to spawn.

A second theory proposes that changes in precipitation patterns in Alberta are creating an increase in the amount of acid rain that falls in that province. As a result, northern lakes are dying, their temperatures are rising, and, as in the first scenario, these changes have modified west coast stream temperatures and scared off, or confused, the salmon who returned to spawn. In any case, the economic has been large enough to have been noticed, and continues to grow (United Nations Climate Conference (2009); Alberta Environment, Fisheries and Oceans Canada (2007)).

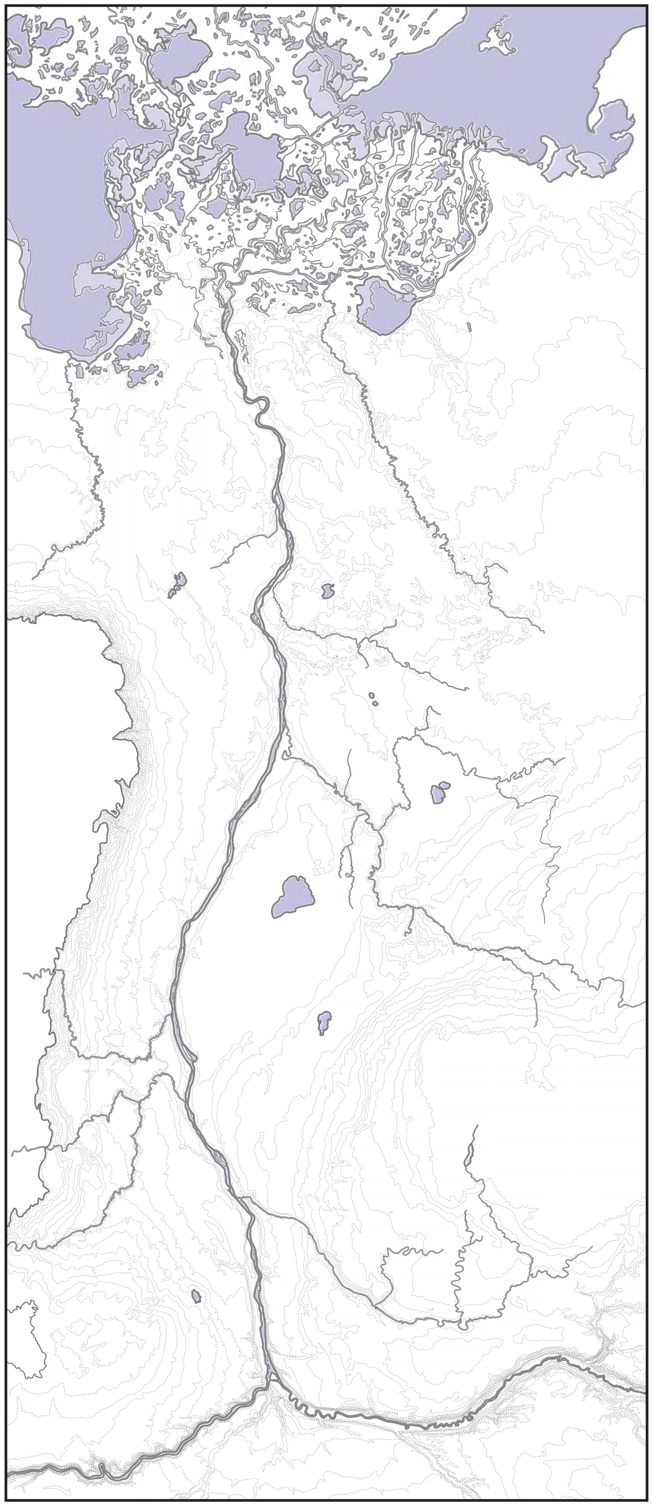
[33] Namely, it undermines the landscape's ability to carry out local ecological processes, undermines the landscape's long-term viability, and undermines the ability of larger systems to carry out their processes.

chapter four

Site Analysis

Site conditions define the nature of any intervention proposed within a site. Having come to terms with wetland processes and structure and the specific effects that development has on both of these above, this Chapter presents a description of site conditions such that the architect can orient himself within the landscape and come to terms with those conditions that constrain, limit, or expand the scope of design possibilities on this site.

Chapter Four is divided into two parts. After a brief introduction, Part One provides an analysis of the large-scale geographical features that shape local site conditions; namely morphology and topography, subsurface conditions, and geological and hydrological behaviour. This analysis will allow us to identify the characteristics of a number of locally occurring hydrological and morphological feature, to predict the presence of a number of other features that are currently unknown or invisible, and to predict how those features will behave at the site. In Part Two, a series of drawings describe local conditions that constrain, limit, or expand the scope of design possibilities on this site. These culminate in a series of diagrams that define the buildable limits of the site.



In Chapter Four we analyze both the site and the regional characteristics that define its morphological and hydrological characteristics. The purpose of this chapter is to provide a general orientation to the site by identifying site features and explaining how large scale phenomenon impact these processes, to explain local dynamics that affect construction or influence our architectural response, and to determine and describe the complex relationships that interact to define the context within which the local wetland is sited. Our goal is to come to an understanding of the large scale generative circumstances that create and shape local site conditions such that we can design an intervention that integrates with both the local wetland and the dynamics that operate to define and shape its context. To that end, the following analysis considers the site at three scales – the local, the regional, and the watershed – and highlights the impact that interactions between geological, morphological, and hydrogeological forces both locally and globally have upon the site.

In the absence of detailed geographical information, or in the case where certain landscape features are hidden or invisible, such an analysis will allow us to predict the presence of a number of structural and morphological features, and to predict how these features will behave at the site. As will be seen, our ability to design an intervention that does not undermine the processes operating within the landscape is directly influenced by the degree to which we are able to predict landscape behaviour and the operation of large scale forces operating on the site. Ultimately the goal of the analysis is to describe the site such that we can develop an intervention that will work in tandem with, and not be overwhelmed by, the large scale forces that define how the wetland operates. Since it is those territorially scaled forces that drive local site conditions, an understanding of these conditions ensures that we will be able to do so. Moreover, by coming to an understanding of the relationship that the local ecology shares with the broader ecological network, we minimize our tendency to introduce any changes that will reverberate through the system and cause damage elsewhere. Thus, the following

Previous page (p76), fig 4.1: An arial view looking north towards the site and the two meanders.
Facing page, fig. 4.2: the last leg of the Athabasca River, joined by the Clearwater River at Fort McMurray, and running north from there to the Athabasca Delta.

analysis begins with a look at territorially scaled hydrogeological forces operating within the watershed.

Since a great deal of detailed documentation describing the hydrodynamics, hydrogeology, and geology of the Athabasca River at this site is not widely available[1], a complete understanding of the dynamics at play in creating the conditions specific to this site had to be reconstructed based on an analysis of the large scale forces that operate there. Such a reconstruction was made possible by determining the geological nature of the river at this site, and by comparing the known characteristics of such a river type against an understanding of riverbed hydrodynamics, and against visible site characteristics. By comparing these scenarios to measurable conditions found on the site, we were able to generate a reconstruction of site dynamics that highlights both site hydrogeology and the hydrodynamic forces at work on the site.

ONE

Within a wetland context, construction is determined by the impact of hydrological forces on the site, the presence of solid ground, the degree and rate at which water is allowed access to the site, and site saturation. It is also determined by site stability, riverbank stability, and site activity[2] (including the migration of landscape features across the site[3]), and the degree to which avulsion and deposition impact the site[4].

Given that these features drive wetland construction, an understanding of the hydrological processes at work within the watershed, together with an understanding of the geological processes that inform the site's morphology and behaviour, will describe the relevant site construction issues[5]. It will also describe subsurface riverbed morphology,

Facing page, fig. 4.3: A satellite image of the site, approximate scale, 1/100 000. At this scale, channels and pools of water are visible, as is eveidence of the moving littoral, transcribed into the site in the form of branchlike pools.

The site itself is located on the eastern shore within the southern meander loop. To the west lies the Wood Buffalo National Park. On the eastern banks north of the site, distinctive white patches along the riverbank reveal where large patches of terrain have been stripped away as a result of avuilsion, or have collapsed as a result of their low bearing strength and their inability to support themselves. A thick layer of sandy alluvial till creates the distinctive white markings.

allowing us to understand how intervention into the water will behave (where impoundment will occur as a result of water speed, direction, and pressure). An understanding of river sinuosity will allow us to determine the shape of the riverbed itself, and come to an understanding of the forces acting against the riverbanks and their erosional strength along the length of the site (and beyond). Such an understanding will allow us to determine the relative strength of the riverbank along the site boundary and to determine which locations are suitable for construction. Using this information we can develop bank sections that mimic and/or augment the current hydrological regime and thus limit damage to the riverbank system. Moreover, an understanding of the hydrological processes acting upon the site will describe how landscape features propagate on the site itself, and in some very specific cases, migrate across the site.

In what follows, then, we will uncover the structural features that create the meandering river-type at this location. Doing so will allow us to describe local site structure and processes, as well as the dynamics of the hydrological and geological processes and the large scale forces that drive and impact the behaviour of local landscape processes.

The Embarras Meander[6] is located at the base of a large fan-shaped glacial till plain that spans four thousand square kilometres of northern Alberta. This gravel-rich, coarsely grained plain extends one hundred kilometres north from the site, and terminates abruptly within the muddy wetlands of the Athabasca delta plain (bound by Lake Athabasca on the east, and Lake Claire on the west).[7]

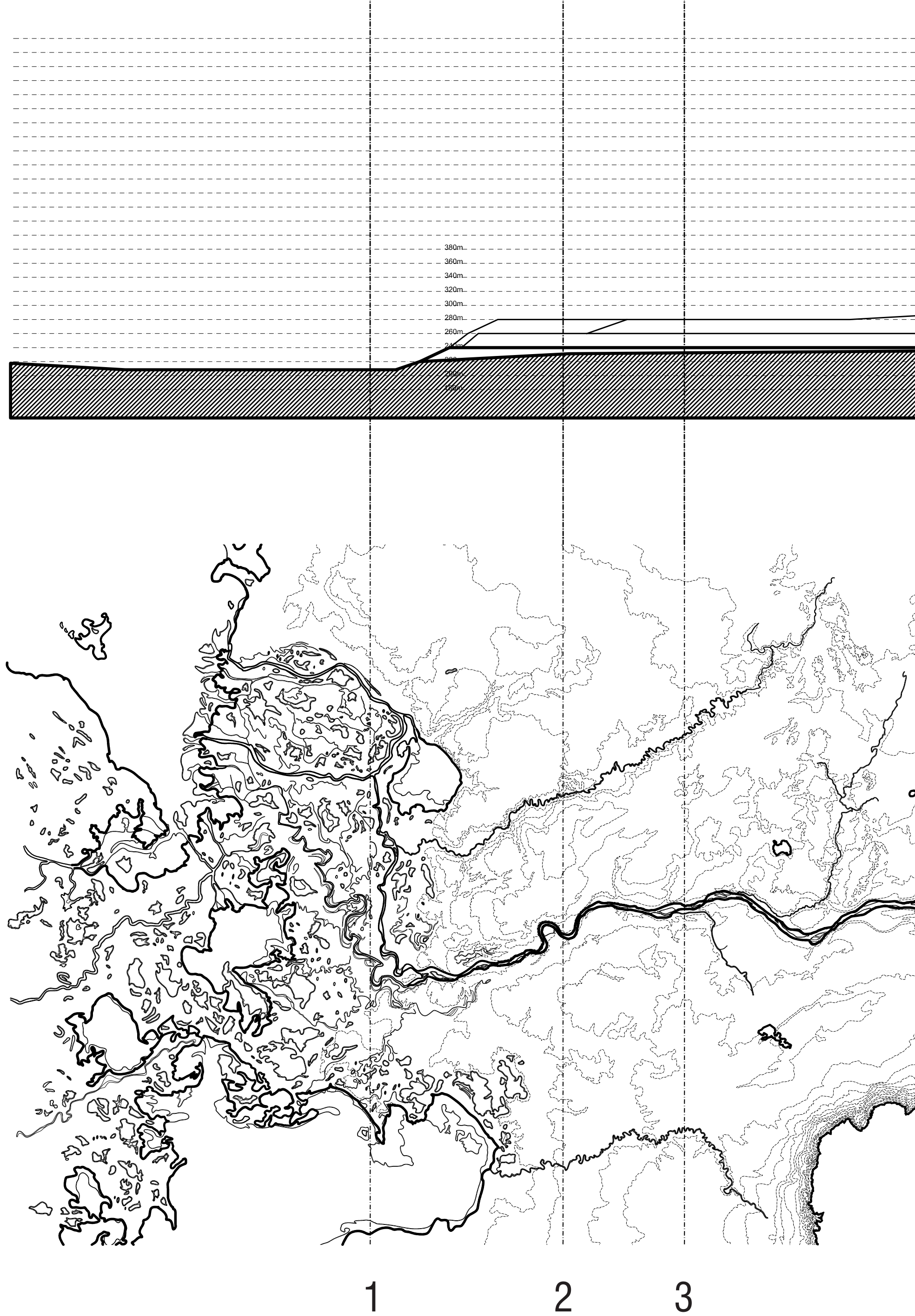
The sudden appearance of a bend in the River at our location confirms that a fairly significant geological event must be occurring adjacent to the site. After all, with the exception of the deflection that occurs at this location, the Athabasca River flows in an almost straight line for the majority of its four hundred kilometre trip from Ft. McMurray to the Athabasca River Delta, and only at this location does it suddenly make a succession of four very sharp and abrupt shifts in direction.

Riverbank hydrology suggests that such a condition can only be caused by a number of geological circumstances (each of which is confirmed by the watershed sections). Specifically, that there is a drastic reduction in stream gradient at this location, and that there is a sudden broadening of the river's bedding width as the river moves from a constricted channel and into the less constrained space of a plain[8]. Our site is, in fact located at the terminus of a long, slow descent, and at the beginning of a second spillway (one which will take the riverbed from the elevation of the Athabasca Plateau to the level of Lake Athabasca). Simultaneously, the site itself is itself listing from the east (at a higher elevation) to the west (at a lower elevation).

The distinct circular curve that we observe at this location is, then, the result of the River negotiating both changes in grade (from north to south) and the list[9]; it is, in effect, a geographically-scaled switchback, negotiating changes in slope in two directions.

Hydrologists refer to this type of switchback configuration as a meander, and identifying the riverbend as such allows us to make several predictions about site conditions[10]. Namely, that unless the riverbed is radically reconstructed, the territorially scaled geological features that define its appearance will ensure that a meander will always occur in this location[11]; that since the kind of abrupt changes in riverbed slope that create the appearance of meanders also cause the river to discharge its sediment load, the site probably sits at the base of a provincially scaled spillway,[12] and thus, will be subject to both regular seasonal flooding and the subsequent deposition of till suspended within those floodwaters[13]; that the north-eastern riverbank is structurally unsound and will continue to erode as a result of fluvial pressure at this location[14]; and finally, that though the meander will slowly shift position over time (from east to west

Following pages, fig. 4.4:
The long section of the Athabasca River (approx. scale 1/1 000 000), reveals a landscape of distinct topographical shifts. Two noteworthy changes occur, one at the base of Alberta Plateau (the high plateau to the right), and again at the limits of the lower Embarras Plateau (where our site is located). It is only at the second location that a meander occurs. Analysis of the east-west section reveals why this is the case.
Note: scale in this drawing has been exagerated by a factor of 100 in the vertical dimension. Though the changes described above do occur, the River's actual slope is 1: 10 000, or 1 metre for every kilometre. A drawing of such a gradual slope would be a straighline.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360m
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1
2
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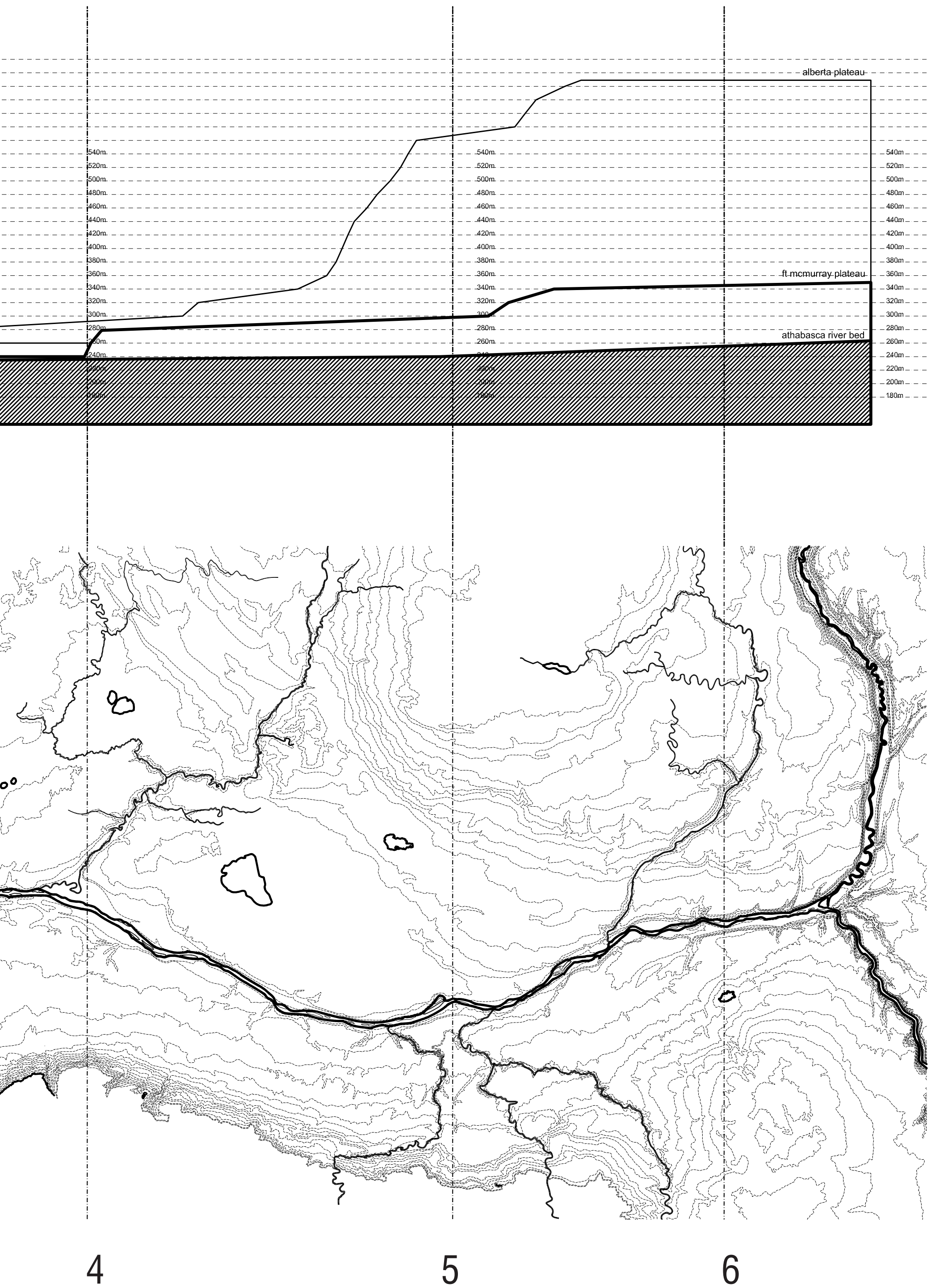

alberta plateau
ft.mcmurray plateau
athabasca river bed
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520m
500m
480m
460m
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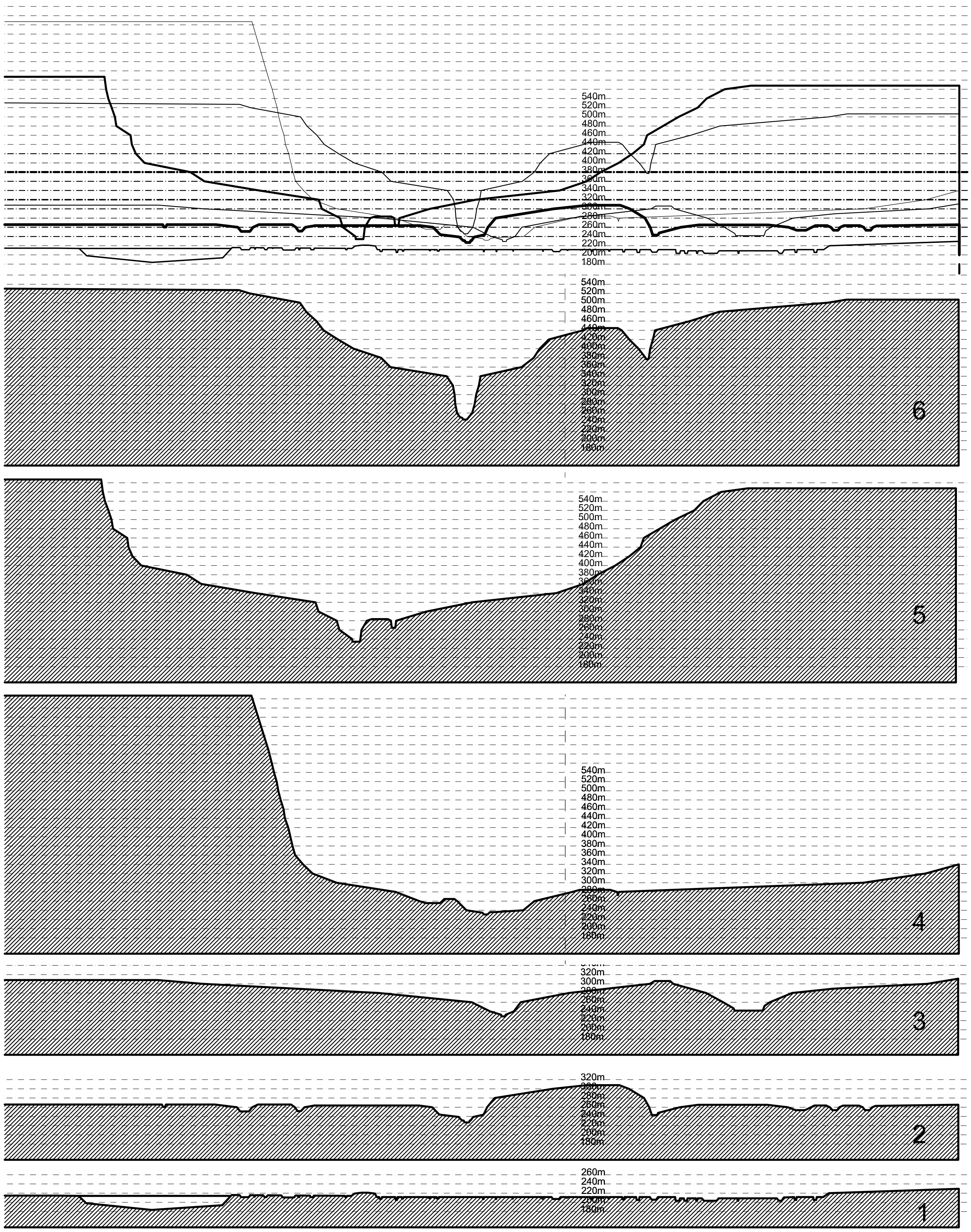
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and north to south, as meanders typically do), it is most likely prohibited from migrating onto the site at the south-eastern bank because of the complex array of forces that cause it to make its first turn westward[15].

Identifying the riverbend as a meander also allows us to make several predictions about the features that occur at the site. The defining feature of a braided riverbank is that both its spatial and ecological relationships are in a constant state of flux[16]; that, because of the movement of water and the unique characteristics of the landscape in which it is found (i.e. that it itself is flexible), its spatial and ecological relationships are both dynamic and constantly evolving.[17] Typically, this makes meander sites ecologically unique in that they allow for rich relationships to be formed above and below the surface of the river (what is referred to as "vertical and lateral hydrological connectivity" by riverbed ecologists)[18], and in that the surrounding habitats, ecotones, and biotic gradients change in response to fluvial processes. The river is constantly changing and creating constant change. As a result, it creates a rich and dynamic ecology.

That the site can be described as a meander also allows us to assume the existence of certain hidden site conditions. Typically, meander rivers are characterized by the presence of multiple channels along the riverbank[19], by the presence of poorly defined and easily eroding banks[20], by the presence of non-cohesive sedimentary material[21], by a high degree of biological connectivity both horizontally across the riverbank threshold[22], and vertically across the surface of the water[23], the subsequent presence of rich surface-subsurface exchange processes[24] and a shifting habitat mosaic[25], by a high incidence of avulsion[26], and by the presence of transgression lineaments.

Finally, identification of the site as a meander system allows us to describe site behaviour that would have otherwise remained unknown. Meander systems, their channels and their braid bars, are unusually and highly mobile[27]. Avulsion and deposition constantly reconstitute both the edges of the river condition and the adjacent landscape as they either tear away erodable till, or deposit it during floods[28]. River and riverbank

Facing page, fig.4.5:
East west sections of the Athabasca River reveal that after travelling in a tight channel across the Alberta Plateau, the landscape suddenly opens to the west as the river descends to the Embarras Plateau. The combination of both the sudden expansion of terrain from east to west, and the drop to the Embarras Plateau create the resulting meander (note: nts, and exagerated 100 times in the vertical).




layouts often change significantly during flood events and across time[29]. Channels have a tendency to move sideways over time (as a result of differential velocity along opposite sides of a riverbank), banks migrate as they are eroded and as the river moves into the new braid channels that are formed during flood events[30]. Transgression lineaments and transgression striations move across sites as a moving littoral redefines the physical properties that drive riverbank formation[31]. In other words, a site located within a meander system is prone to ongoing potential massive reorganization as a result of the hydrological forces that constitute it.

We must be aware of these features, of course, because not only does each of them have a direct impact on the nature of the proposed intervention and its relative buildability, but each of them constitutes a structural feature of the local wetland and the river ecology. The relationship these conditions maintain with wetland structural features (the timing of processes, the interaction of geological effects that bear a direct impact on biological processes and relationships) defines the nature of the adjacent wetland itself, and thus, represents one more set of interconnected features that drives the ongoing stability and viability of the adjacent wetland. As it turns out, it is the presence of features that are constantly undergoing ongoing and constant change -- "undergoing maximal… exchanges"[32] – and the ability of local plant and animal life to absorb and adapt to that change that create the complex ecology and biodiversity that characterizes this kind of wetland site. As such, any strategy that aims to integrate with pre-existing ecological systems will not only need to negotiate these conditions, but will have to be flexible enough to allow them to continue to operate; to be robust enough that it will instigate changes that allow the wetland to adapt to its new conditions, while simultaneously giving that wetland the space it needs to continue to operate in a way that would, specifically, seem to undermine the presence of an ordering structural system.

Facing page, figs. 4.6 - 4.9:
Typical riverbank conditions along the Athabasca River north of Bitumount. Clockwise from top right: The characteristic image of the boreal forest, defined by the presence of short and scrubby black spruce, tamarack larch, and balsam poplars. The eastern bank of the northern meander is heavily scarred by the affects of avulsion; erosion and subsequent landslides have revealed the sand facies that form the underlying strata of the site. A riverbank adjacent to the site. Banana shaped ponds and striations characterize a portion of the bank immediately south of the site (on the eastern bank at the apex of the first bend).

TWO

The analysis conducted above sheds light on the territorially scaled forces that play a direct role in constituting landscape behaviour at the level of the site. Such an analysis not only clarifies the specific physical conditions that describe the site, but also foregrounds those features that define local conditions, thereby allowing us to predict the presence of unknown local phenomenon and to predict local behaviour. The analysis allows us to understand the complex relationships that interact in order to create those particular conditions, and ultimately, that will allow us to design a strategy for sustainably integrating urban development into the wetland landscape. Moreover, it will ensure that the effects brought about by the implementation of those strategies will work in tandem with local conditions and will not be overwhelmed by large-scale territorial forces (such as avulsion or flooding). In what follows we describe the presence of local conditions and the interactions that take place between these and the large scale geological, morphological, and hydro-geological forces identified above.

In morphological terms, the Embarras Meander is a captivating site for a number of reasons. While defined by the interaction that occurs between large scale territorial forces and local conditions – between those forces that define the broader river system, and those that create the adjacent wetlands – the site is simultaneously undergoing continuous transformation as it is acted upon by local hydrological and geological forces. Much of this change is quite clearly expressed by the terrain itself. Along the riverbank, hydrological pressure creates an array of unique geological features including braid bars, dunes, laterally accumulating floodplain sediment, and washover remnants. Slightly inland, alluvial pressure interacts with landscape features to displace the shoreline and reposition it laterally (a process referred to as ongoing migration of the riverbank littoral)[33]. Over time, the build up of gravel and loose sand

Facing page, fig. 4.10:
A photograph of the site, looking south across the northern meander. The twisted landscape of the northern meander is apparent in this photograph, as are the effects of erosion on the eastern bank (on the left). Even at this scale, the jagged condition of the site is apparent; hummocks, low hills, deep channels and ponds, and braid bars appear as contrasting bands of green. A remnant of an ice road is visible as a cut-line among the trees in the lefthand foreground. For scale, consider that the river is 800 metres wide at this bend, and the eastern cliffs are 6 stories tall.

at the edge of this moving shoreline front creates a series of distinctive dune-like ripples in the landscape, and ongoing pressure from the bank causes these to migrate across the site[34]. The resulting movement creates the distinctive striped patterns – or transgression lineaments – that appear on satellite images of the site's north-western floodplain.

Further inland, the ground plane undergoes constant and ongoing reshaping. The freezing and thawing of subsurface water dislodges chunks of peat to create large dome-shaped hills, and seasonal flooding deposits sediment across the south-eastern half of the site on an regular basis[35]. The movement of water through this silty terrain creates rough hewn channels that mark most of the centre of the site. To the northwest, the river bank and adjacent floodplain are prone to avulsion, a process whereby large tracts of landscape are forcibly separated from the bank and carried away by the river[36]. These sudden transformations are mirrored by slower ones that include riverbank liquefaction as a result of subsurface wave activity[37], riverbank slumping as a result of gravity processes[38], and the rearrangement of riverbank and bedding surfaces as a result of flooding and channel shifting on the site[39].

The diagrams that follow describe local site conditions. These conditions affect not only the buildability of the site and the techniques that will be used to build there, but they describe conditions that will influence the specific conditions and elements of the design intervention. As such, they act as a baseline for orientating ourselves within the landscape, for coming to terms with local conditions within the site, and for determining the nature and specific characteristics of the strategies we will design in order to integrate the urban development into the local condition. The diagrams conclude with a summary of site conditions that constrain, limit, or expand the scope of design possibilities on this site, and with the development of a series of diagrams that define the buildable limits of the site.

Facing page, fig. 4.11:
Looking north along the Athabasca River; site conditions 100 kilometres south of the site.

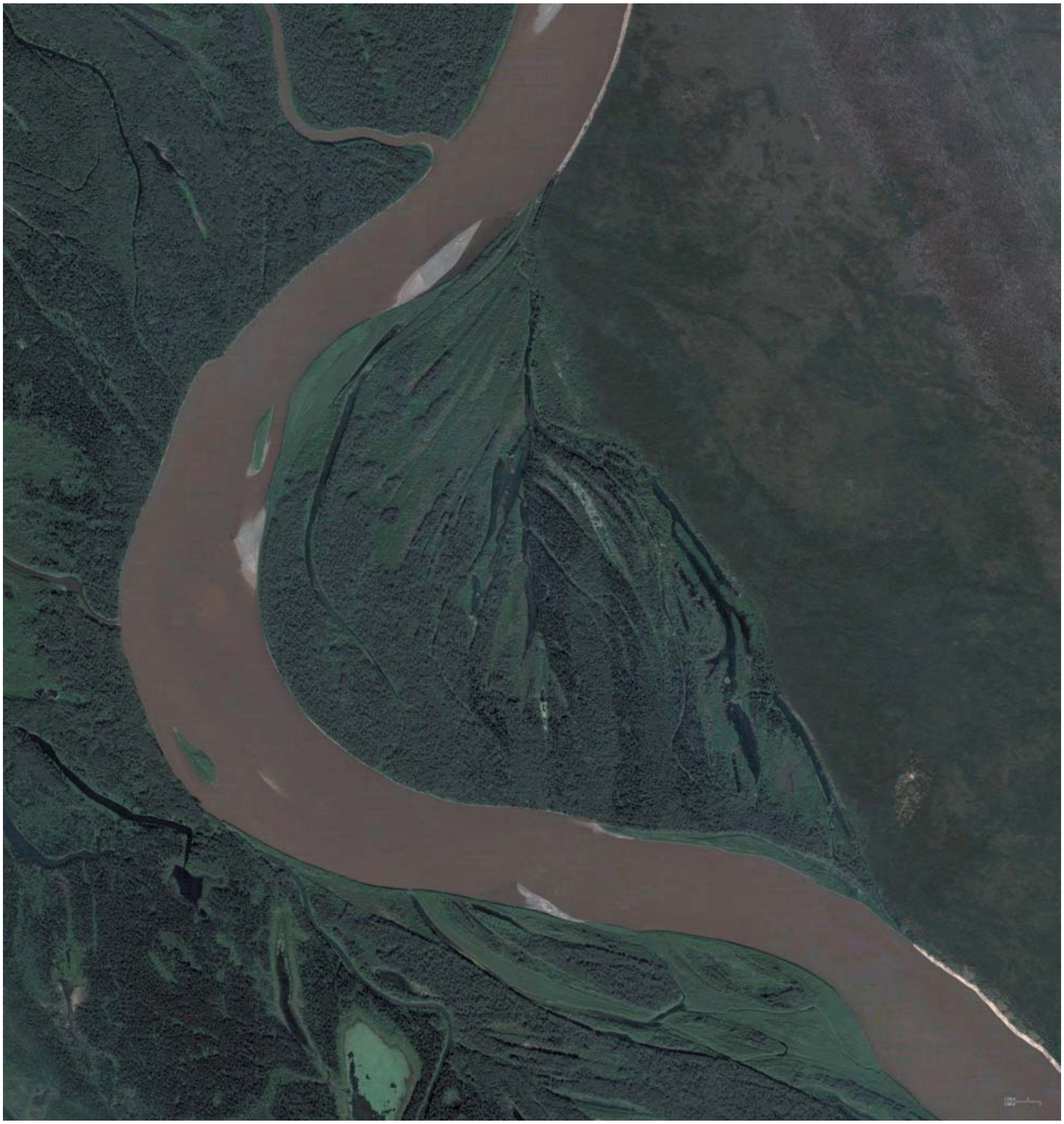


Fig. 4.12: The site lies in the eastern elbow of the meandering Athabasca River. Wood Buffalo National Park is located on the west bank.

The site plan reveals a river negotiating a marshy channel distinguished by an abundance of surface water that takes the form of long thin pools and snakelike bodies. It is enclosed on the east by a subtle slope, and along the riverbank by a lip-like bank. Distinctive braid patters and banana and feather shaped traces of laterally accumulating sediment indicate the River's tendency to interact with the adjacent landscape, and to wander within its path. (scale approx. 1/25000).

Fig. 4.13: With the cover of trees removed, the degree of groundwater that covers the site becomes clear. A swath of thin pools bisects the site at the base of the eastern slope. Though the river bends away from the slope, it is clear that it may once flowed directly across the site. The pools form a distinctive branch pattern as they move through what is most likely a field of marshy river-deposited sediment and till. The channels describe the underlying pattern of hummocks that rise up through the marsh.

At the north-eastern edge of the site, the water fills long slender channels indicative of transgression lineaments. The ground here is probably nothing more than a bed of till floating on a shallow pool or sluggishly moving branch of adjacent river. The transgression lineaments indicate that the riverbank is in the process of shifting from its current position and moving into a new channel -- or is in the process of moving from a previous position -- as hydrological and geological forces exert pressure upon it. (scale approx 1/25000).

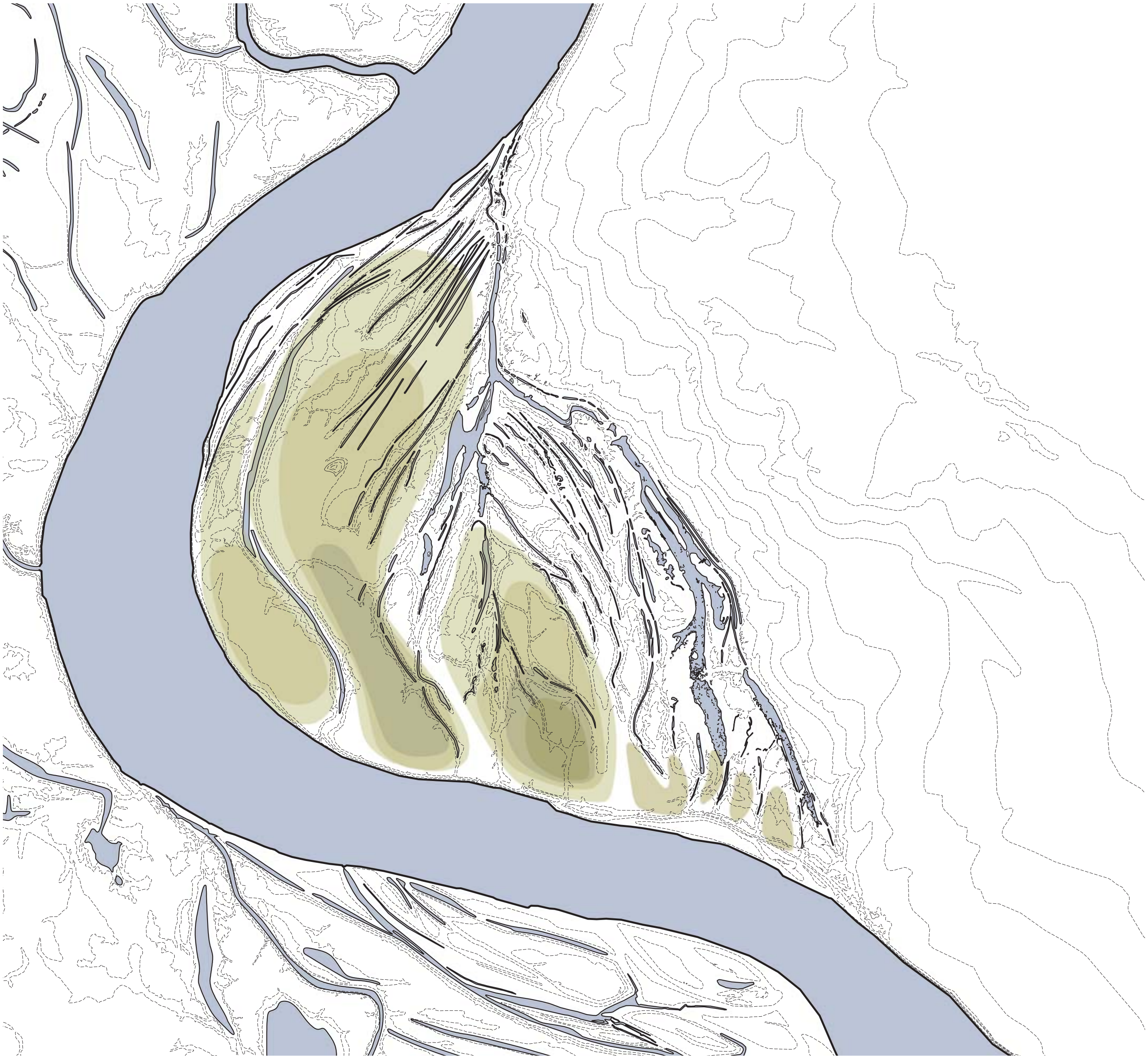
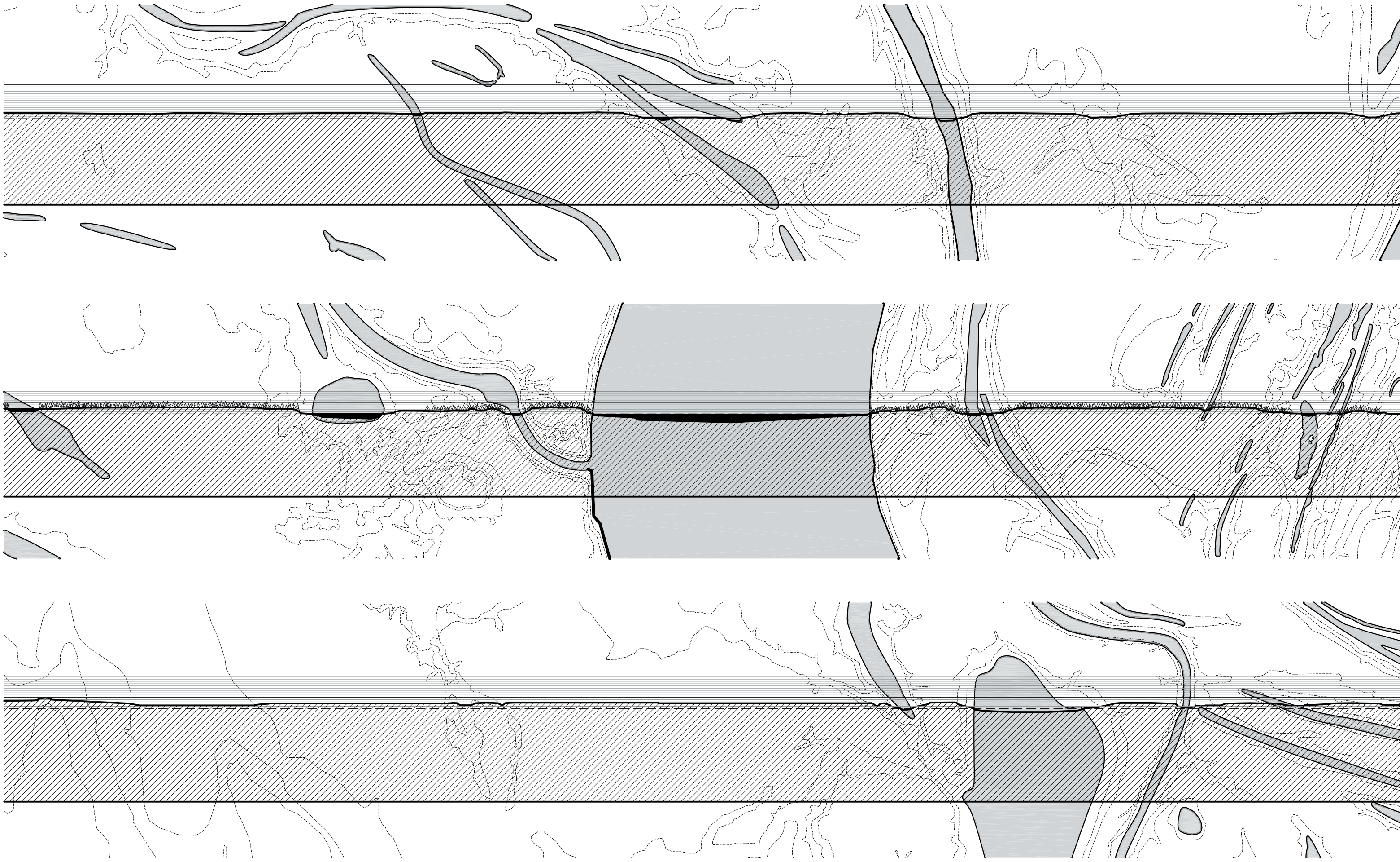
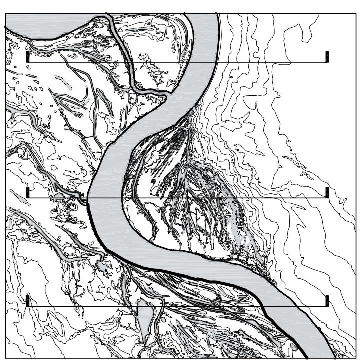


Fig. 4.14: Local Hydrology and Contours
The diagram illustrates the relationship between ponding and the presence of hummocks on the site, as well as areas of higher and lower ground (high ground is highlighted). A distinctive branch-like structure is revealed, which indicates the presence of a palsa mire and gives some clue as to the structure and composition of the site (scale approx. 1/25000).

Fig. 4.15: Illustrates the general morphology of the site, and highlights the differences in zones within the site. The presence of a protective bank is indicated in A, and a bowl occupies B (see sections below). C is characterized by a fen-like landscape, whereas B is predominantly swampy wetland.





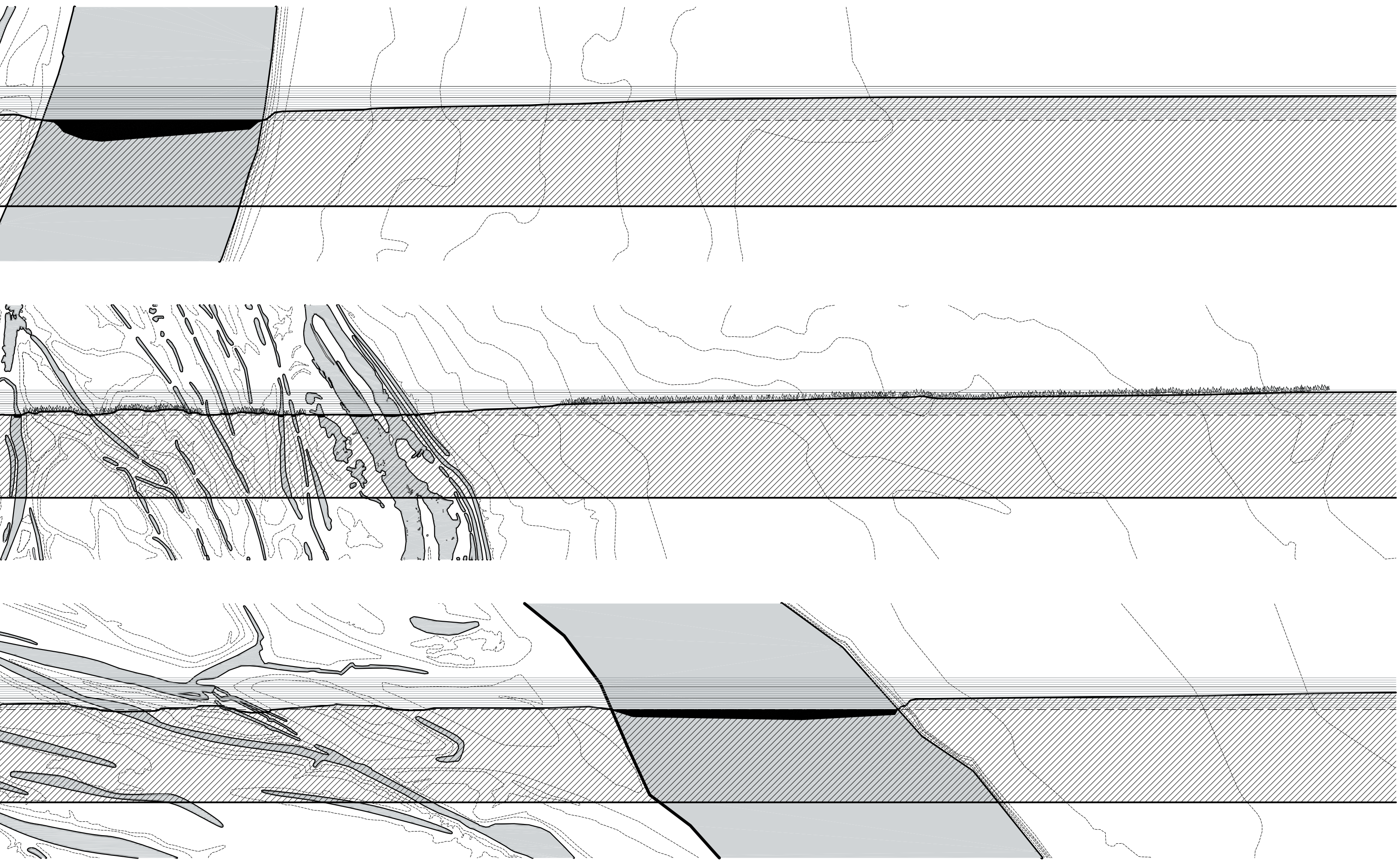
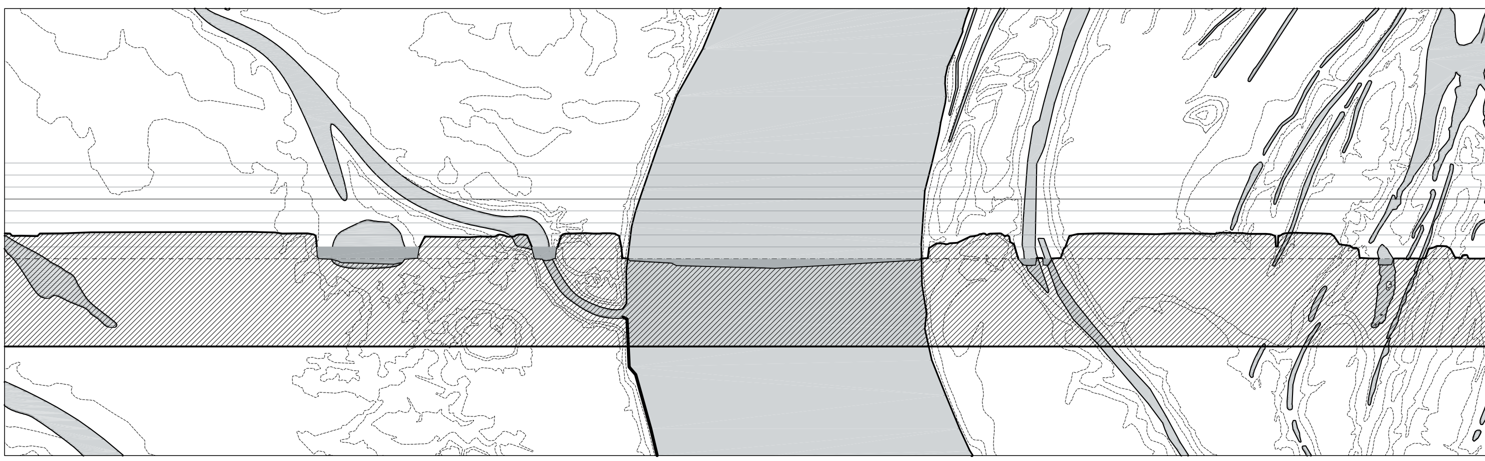


Fig. 4.16: Site Sections
At this scale, sections illustrate the site's relative flatness. Low banks to the east and to the west (these banks rising steadily to form the Birch Mountains) form edges within which most of the deposition and hydrological activity occurs. (scale approx. 1/15000).



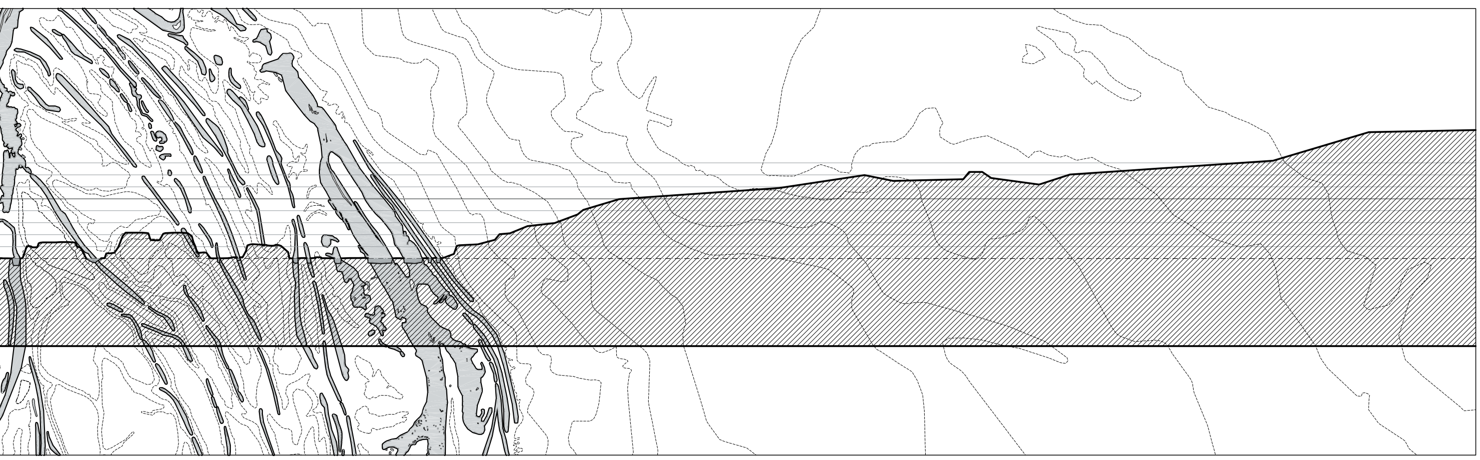


Fig. 4.17: Exagerated Site Section
When exagerated 5 times in the vertical dimension, the second site section from the previous page reveals the flat Embarras Plain to be an expanse of low, domed outcroppipngs rising out of a landscape of marshy pools, streams, and waterlogged (deposited) alluvial drift.

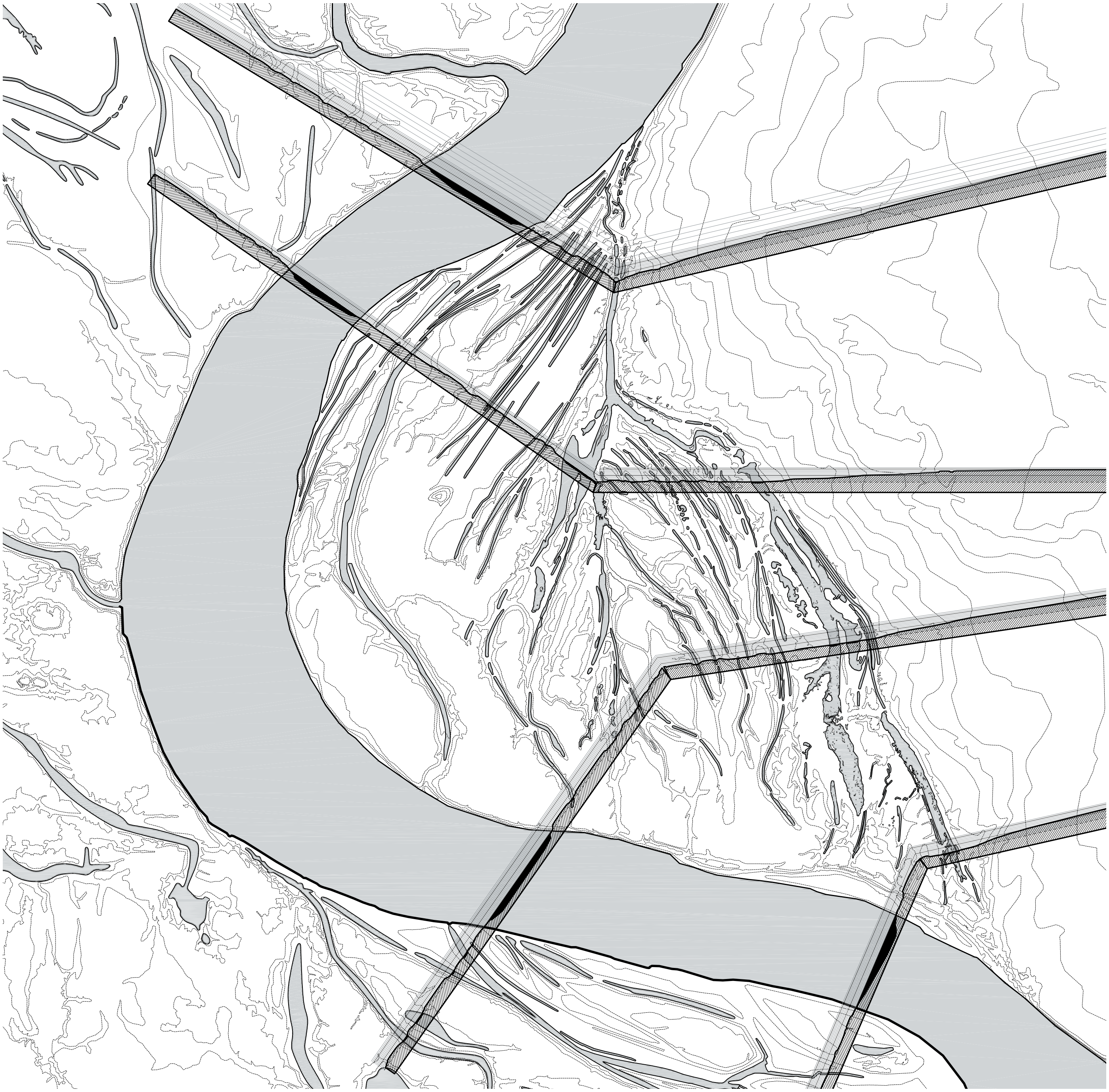


Fig. 4.18: Site Sections
The sections reveal the differences that characterize the eastern and western halves of the site. The centre and the eastern half are marshy, waterlogged, jagged, and low, whereas to the west the spur that forms the edge of the bowl is flatter, less active. To the northwest the site begins to form what can best be described as ripples, a characteristic sign that bars of sedimentary till have begun to compress under pressure from ongoing deposition.

Like lines that define orbits of ever increasing gravitational intensity, the characteristic ripple effect clearly indicates the formation of a structure of concentric drawdown curves. When inundated, these ripples, and the hydrological pressure created by the water's action against each of their banks, will lure the River out of its current path and towards a new one. This will create new braid strands along the River's edge, and these strands may eventually draw the River out of its current course and into a new path. If the River migrates in the future, it will do so according to structural patterns that are already inscribed on the site.

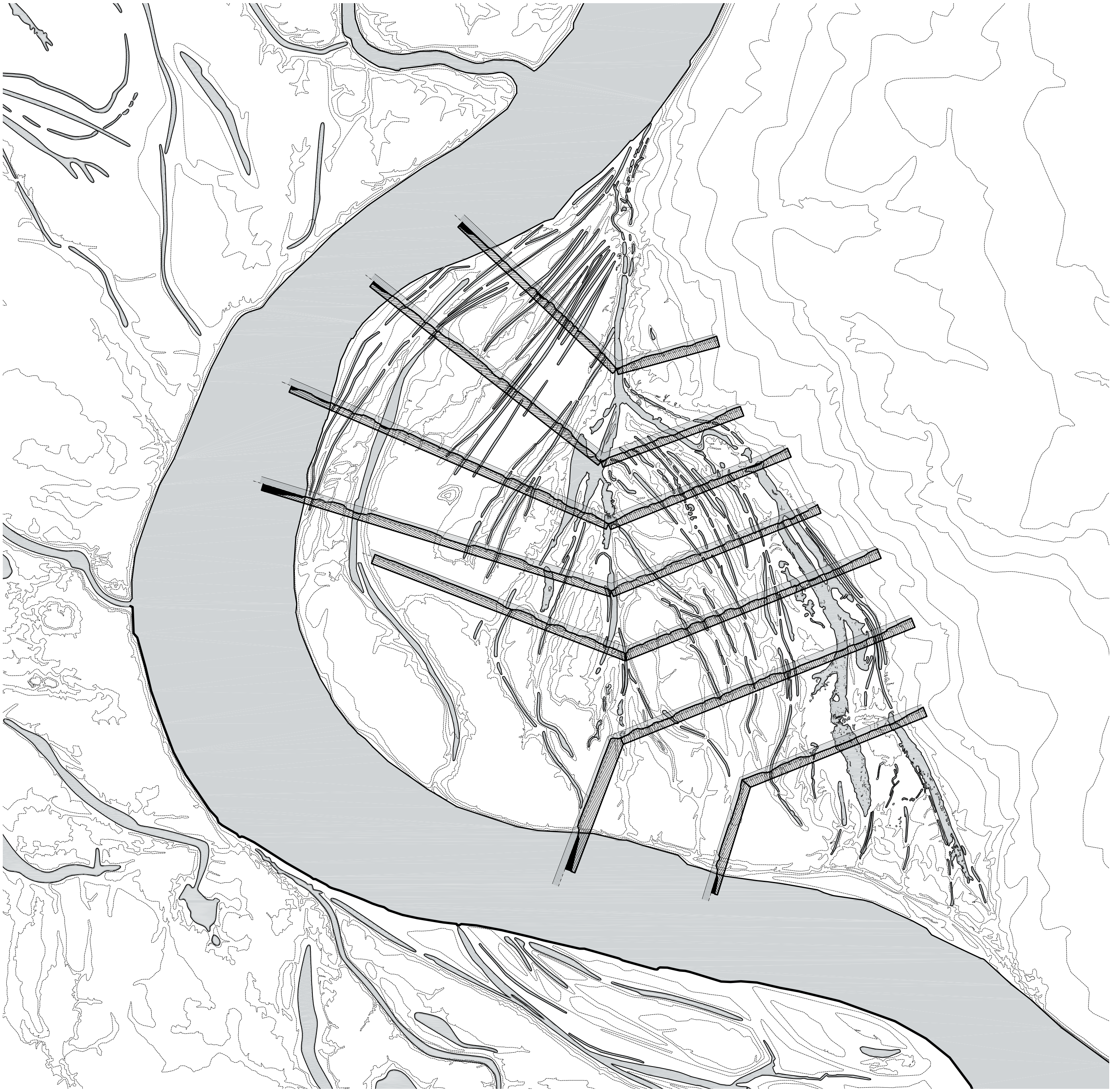
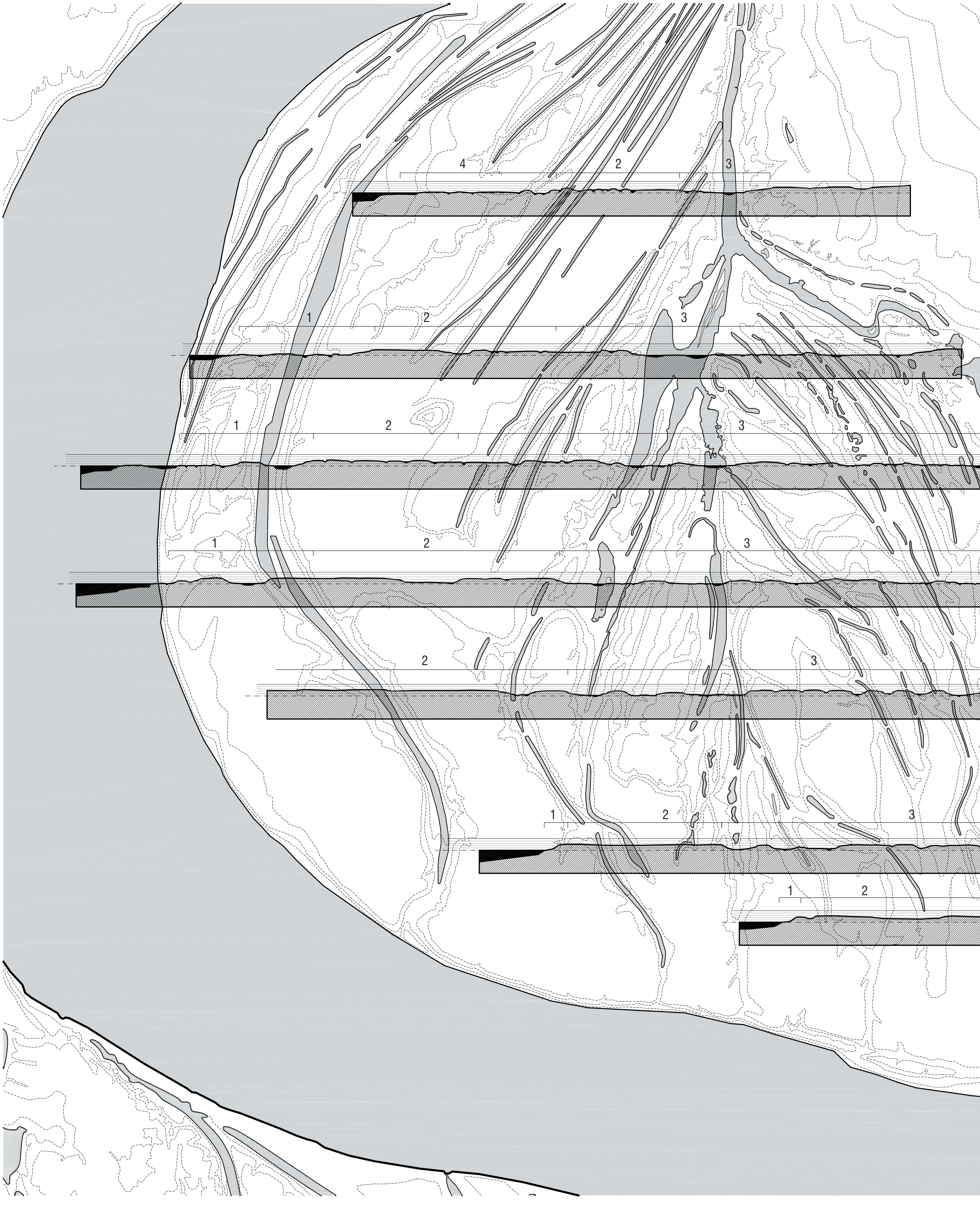


Fig. 4.19: Site Sections
The sections reveal the presence of a hard spur of rock that forms a distinctive lip formation on the site's bankside, and a depression that runs like a crack through the middle of a bowl. The site is jagged, punctuated by hummocks and carved by long pools of standing water and transgression lineaments, traces indicating previous periods of inundation by the river. See 4.20 for detail.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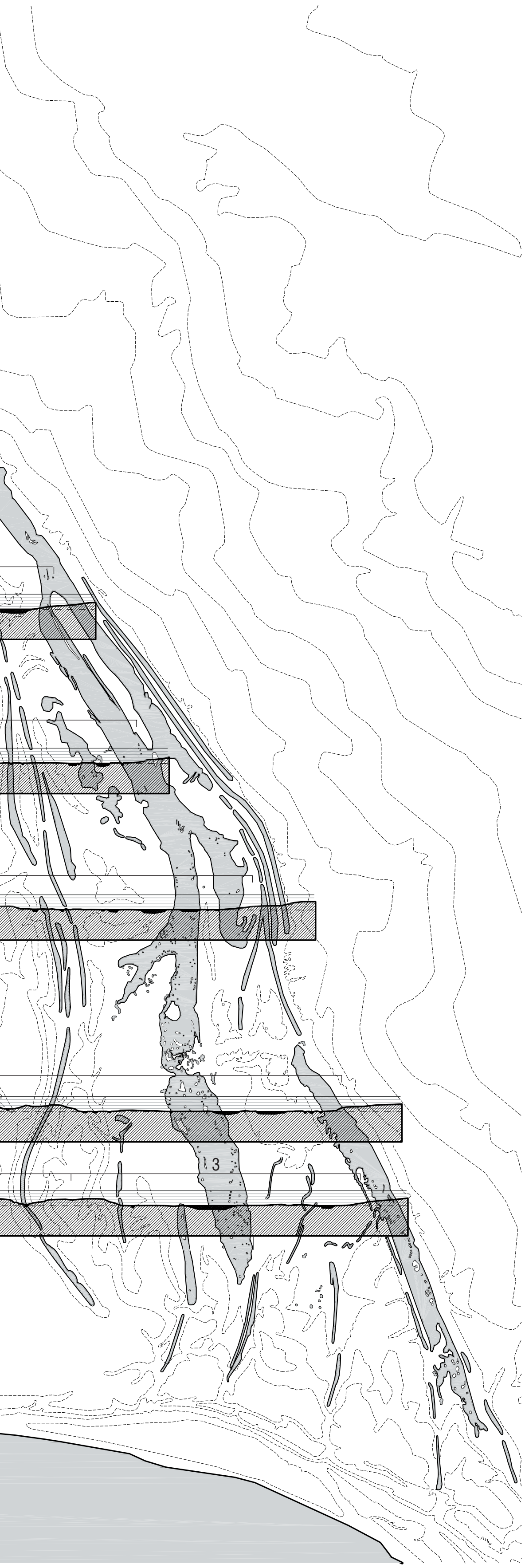
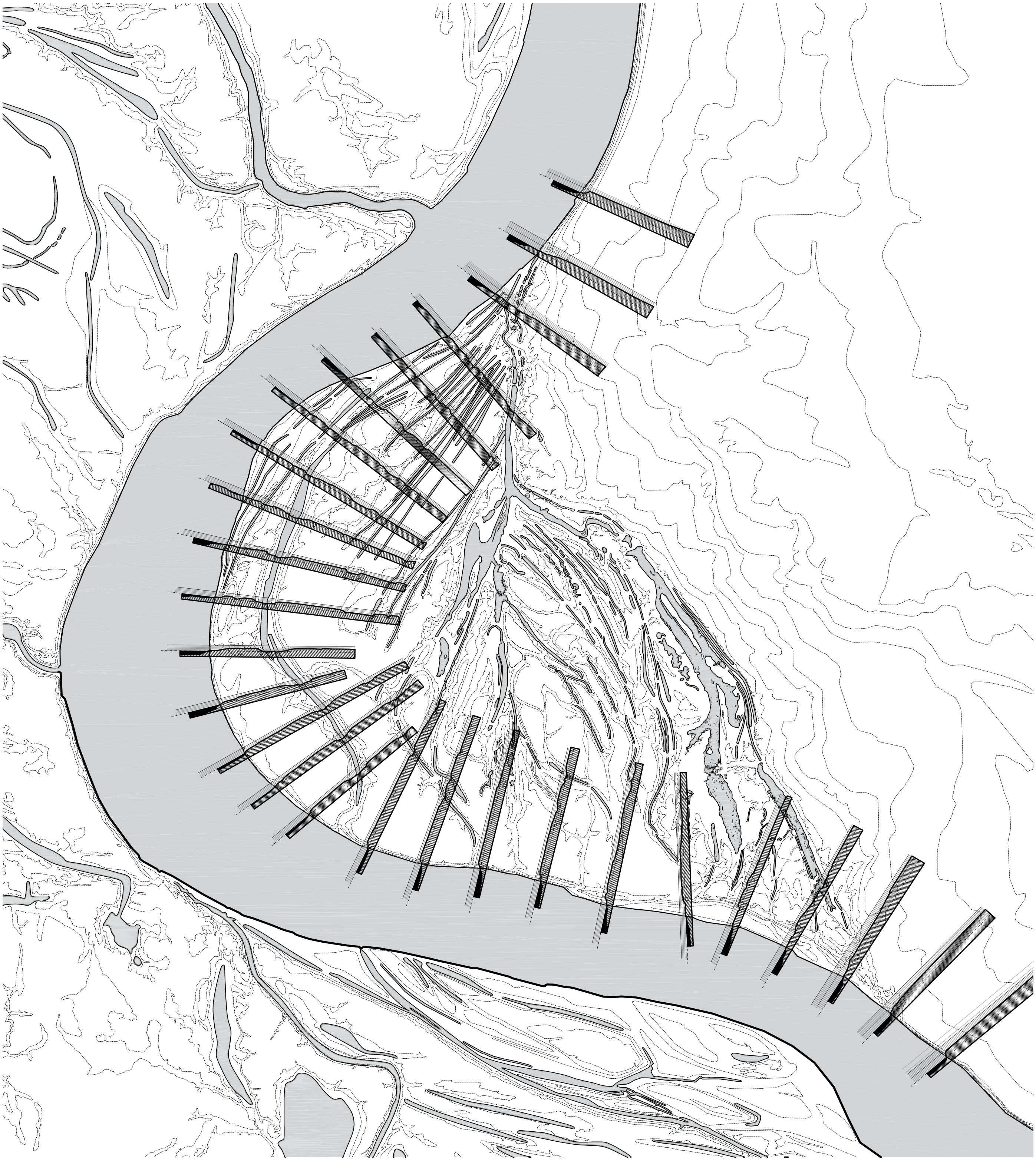
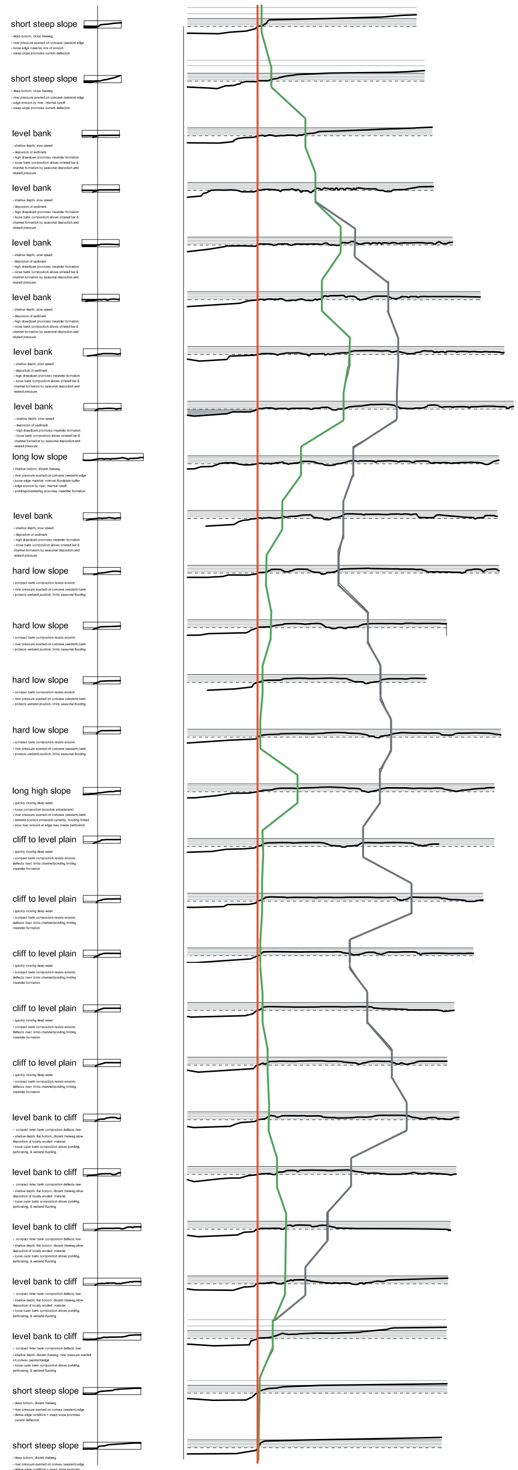


Fig. 4.20: Sections from fig. 4.19, unfolded at approx. 1/10000.
The eastern slope forms a distinct edge adjacent to the pools. The contrast between conditions on this slope and those onsite (characterized by the presence of water and channels) clearly indicates the extent of alluvial deposition. The site is a bowl, hemmed in by a large bank on the west and by the slope on the east.
1. Riparian Zone
2. Bank
3. Bowl
4. Deposition Plain



This page, fig. 4.21: Bank Sections
A series of sections describes the variety of edge conditions along the bank.

Facing page, fig. 4.22:
When stacked vertically, the differences in bank morphology, lip width, bank height and width, and bowl size can be clearly seen.
The shape, relative hardness, height and depth of the bank define its relative porosity. With the exception of a few openings the bank is not porous along the southern edge. Towards the north, bank heights recede and the edge condition is now defined by as a low-lying till plain slowly undergoing compaction by layers of newly deposited till.

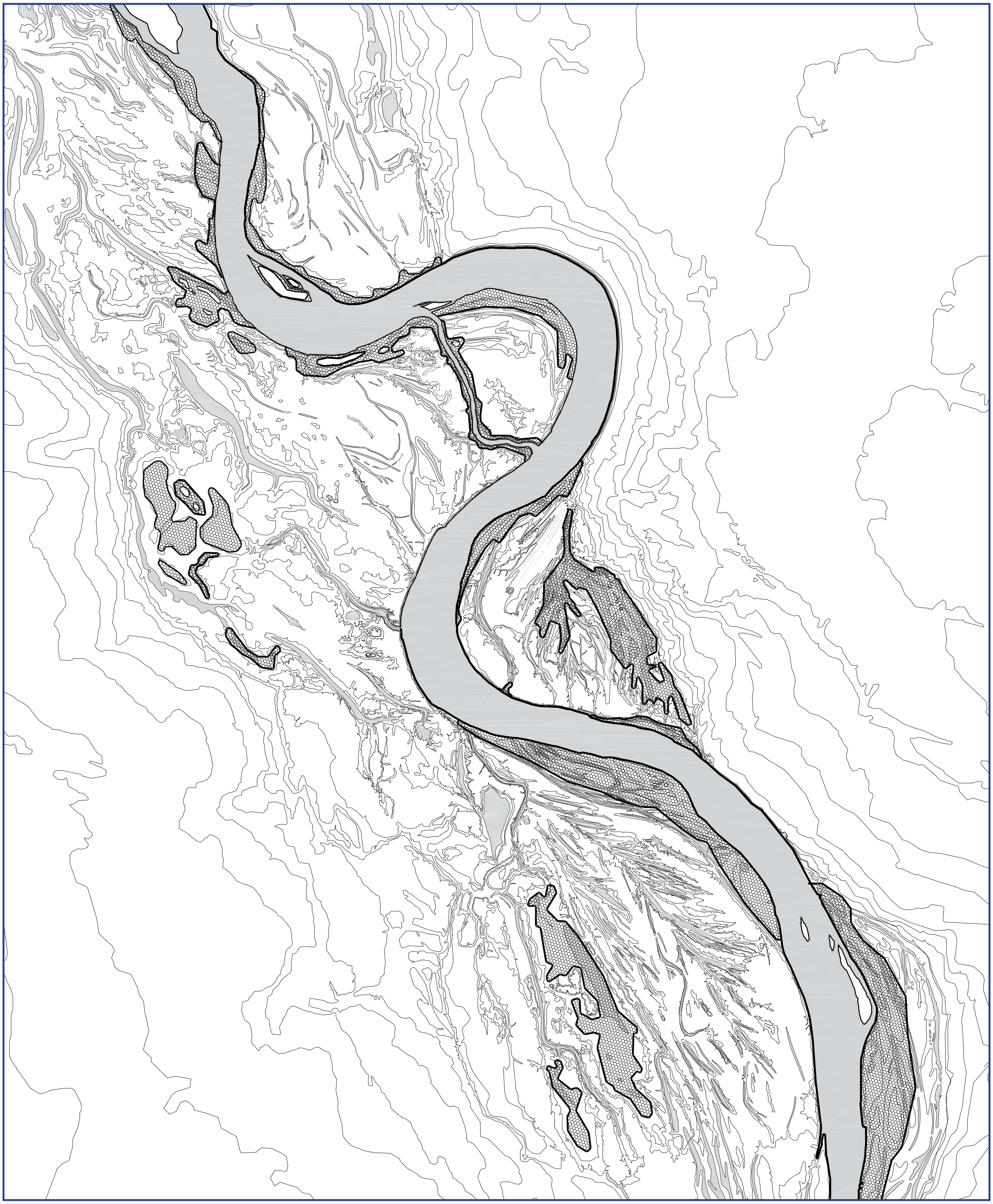


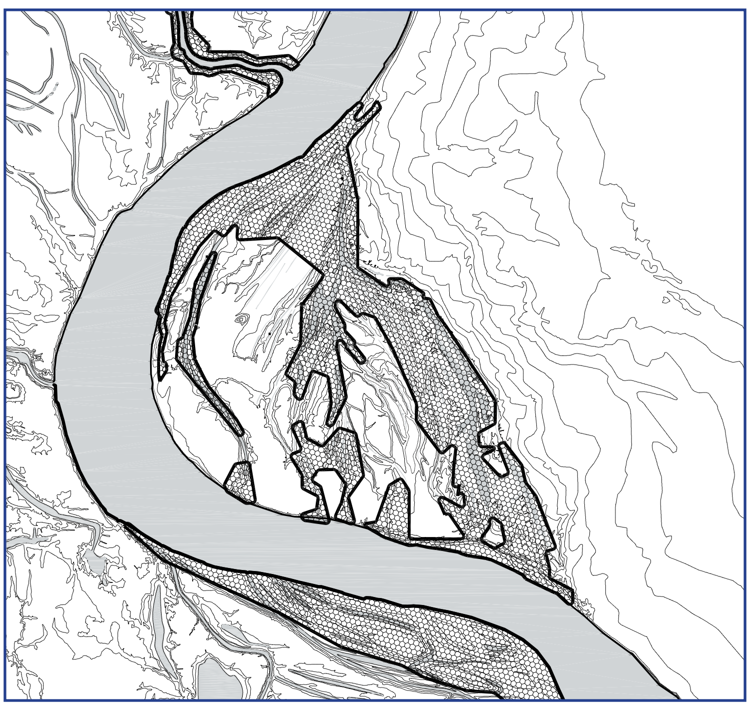
meandering thalweg
(left of red line)
- rapidly decelerating speed & decreasing depth
- south-east bank promotes deflection & entrainment; west bank promotes deflection; north-east bank promotes deposition

bank edge
(between red and green lines)
- steep southeast bank allows erosion, deflection, perforation & seasonal flushing
- level north bank allows seasonal flooding
- level north bank pocked by parafluvial ponds and channels increasing drawdown and promoting meander formation
- high west bank maintains current deflection

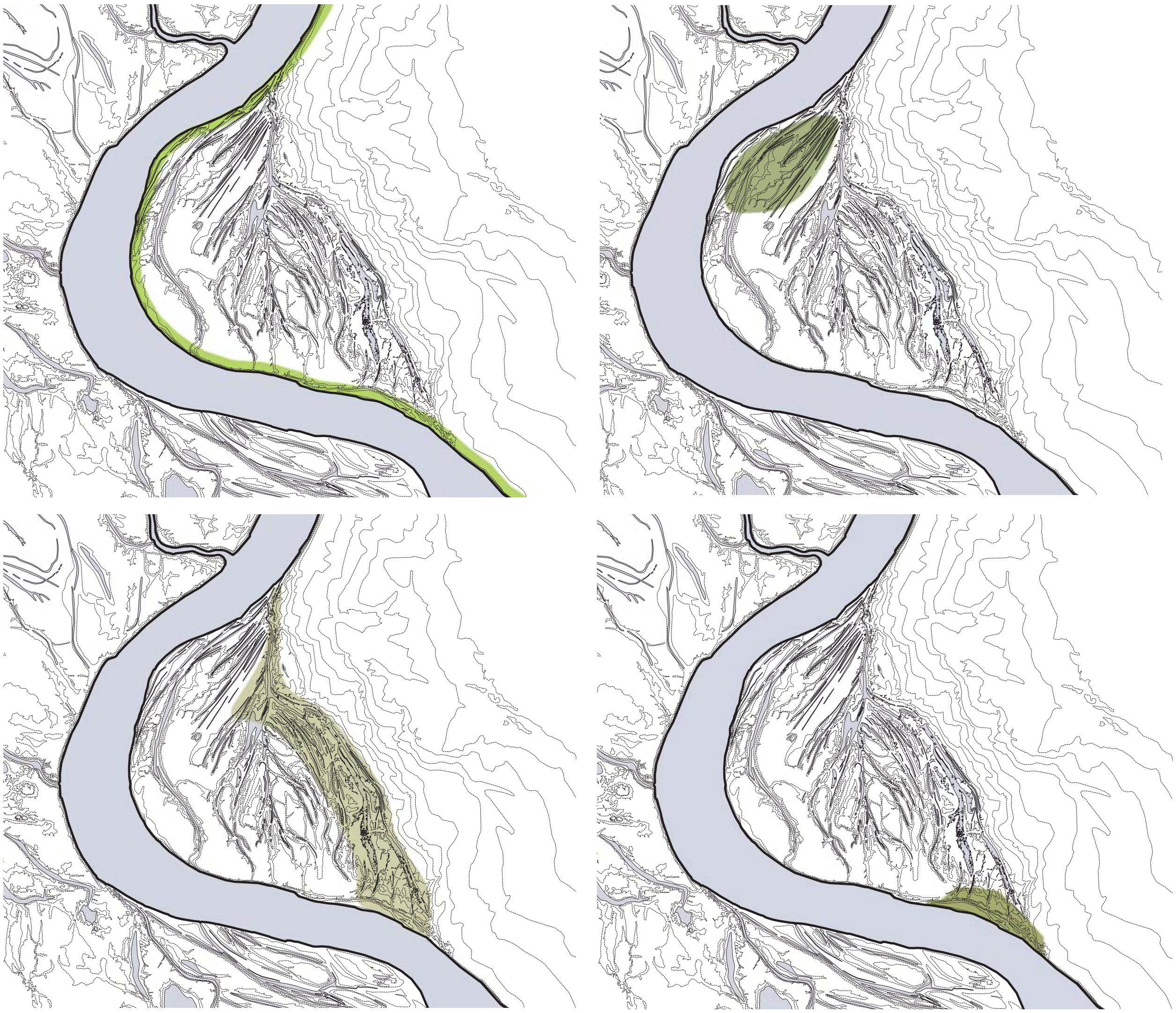
intermediate plain
(between green and blue lines)
- south-east plain perforated by channels allowing seasonal flushing
- west plain depth prevents water penetration
- north plain elevation promotes channel formation and ponding
- northeast bank lacks broad buffer plain

bowl inside bank edge
(right of blue line)
- southern channels draw water into bowl, restrict flow back to river
- abrupt west edge protects marsh position & saturation
- laterally accumulating sediment bars and channels at north bank promote meander formation & marsh perpetuation





Figs. 4.23 - 25: Flooding
The site is affected by seasonal flooding patterns, which replenish and interact with the wetland. Flooding is a direct result of the interplay between river braiding dynamics, subsurface geology, subsurface water migration, channel mechanisms (both subsurface and surficially), and parafluvial pond dynamics
Flooding has a direct effect on surge within the local channels, on the creation of parafluvial ponds; on ground water patterns and how these interact with channels and ponds; the degree to which water drains from the marsh.
Fig. 4.23: Illustrates average extent of flooding along the river corridor during spring thaw.
Figs. 4.24 - 25: Illustrate typical conditions on the site (top), and seasonal extremes (bottom).



Clockwise from top left
Fig. 4.26: Protected Riparian Buffer
Illustrates a sixty metre buffer zone that should remain protected in order to ensure a) the ongoing operation of riparian and refugian actions along the riverbank, and b) in order to ensure ongoing drawdown activity and parafluvial ponding along the riverbank.

Fig. 4.27: Deposition Plain
Illustrates zone of most active ongoing deposition.

Fig. 4.28: Protected Inland Wetland Corridor
Illustrates the intention to maintain a wetland zone within the site. This will ensure that drawdown activities will continue to occur within the site, and will create a wetland connection between the southern and northern boundaries of the site.

Fig. 4.29: Water Access to Site
To ensure seasonal flushing and replenishment, this zone should remain unobstructed.

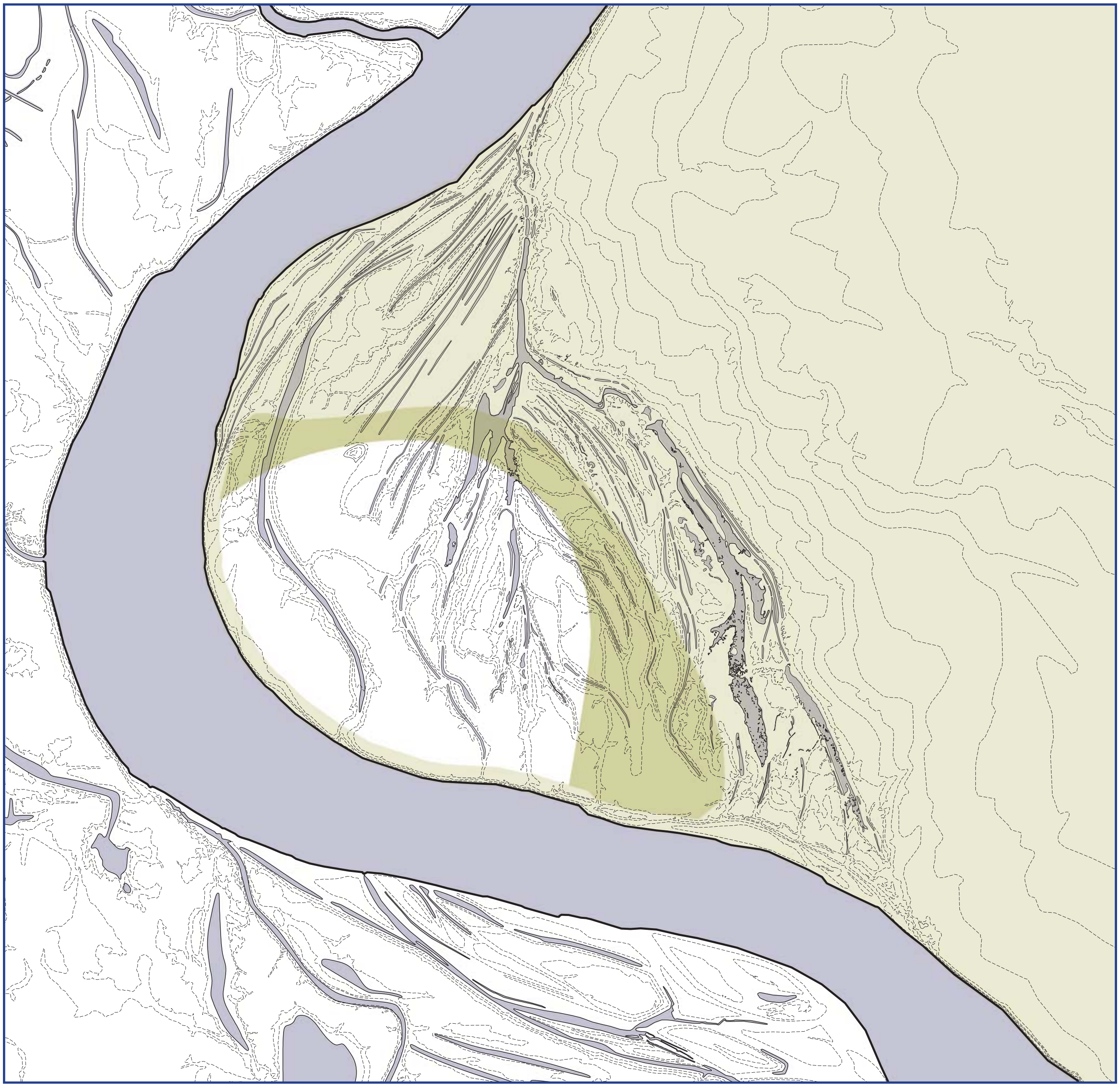


Fig. 4.30: Buildable Area.
This diagram consolidates the previous four to outline the protected area on the site. As well, it indicates the intention to maintain a significantly sized naturalized zone within the site. It indicates where urban development would be least intrusive.

Figs. 4.31 - 32: Atypical dry conditions at two locations on the highground at the southern edge of the site. In the picture on top, looking south, the riverbend can be made out in the top right corner.

Footnotes

[v1] We are referring specifically to material that would detail subsurface geological conditions, wetland structure, bank structure, fluvial pressure, flooding rates and frequencies, subaqueous conditions, and quantified hydrological patterns and their immediate effects on the adjacent landscape.

[2] Hagerman and Williams, 2000.

[3] Such active features include the migration of laterally accumulating floodplain sediment, transgression lineaments, the moving littoral, and riverbank migration.

[4] And of course, given the context of this thesis specifically, construction is also determined by our goal to integrate with, and avoid causing damage to, wetland structural features.

[5] Including bank stability and the location of wetland structural features such as drawdown curves and parafluvial ponds.

[6] Pronounced "awmbraw".

[7] Rhine and Smith, 1988.

[8] Conly, Crosley, and Headley, 2002.

[9] Hamilton, Price, and Langenberg 1999.

[10] Mackin, 1956.

[11] Ibid.

[12] McPherson, Shanmugam, and Moiola, 1988.

[13] Tockner, Paetzold, Karaus, Claret, and Zettel, 2004.

[14] Mossop and Flach, 2003; Postma, Babic, Zupanic, and Roe, 1988.

[15] A spur of rock seems to protect the south-eastern bank from the forces of avulsion, and the western bank is more accepting of water pressure and capable of a greater drawdown curve (this much seems evident given the amount of marsh activity occurring there). These two features combine to cause the river to deflect to the west at the site's southern periphery. At the site's northern periphery, the deflection of the river back on itself (and towards the east) must be the result of a flattening out of the bowl through which the river is flowing, accompanied by a decrease in riverbed slope. This is augmented by grade conditions on the north-eastern bank (on the site side) where bank conditions are much more absorptive than those across the river, and which draw the River in this direction. See Postma, Babic, Zupanic, and Roe, 1988.

[16] Ward, 1989; Tockner, Paetzold, Karaus, Claret, and Zettel, 2004.

[17] Ibid; Ibid.

[18] Tockner, Paetzold, Karaus, Claret, and Zettel, 2004.

[19] Mackin, 1956.

[20] Ott, 2004.

[21] Ibid.

[22] Wrona, Prowse, Beltaos, Gardner, Gibson, Granger, Leconte, Peters, Pietroniro, Romolo, and Toth, 2006.

[23] Ibid.

[24] Tockner, Paetzold, Karaus, Claret, and Zettel, 2004.

[25] Ibid.

[26] Collella, 1988.

[27] Mackin, 1956; Hagerman and Williams, 2000.

[28] Government of Alberta, 2007; Trimble, 1997.

[29] Thorne and Lewin, 1979.

[30] Trimble, 1997.

[31] Lee, Jo, and Chu, 2006.

[32] Tockner, Paetzold, Karaus, Claret, and Zettel, 2004.

[33] Conly, Crosley, and Headley, 2002.

[34] Hyung and Yong, 2006.

[35] Nemec and Steell, 1988.

[36] Rhine and Smith, 1988

[37] Orton, 1988

[38] Collella, 1988.

[39] McPherson, Ganapathy, Moiola (1988) cite 19 authors who conclude that "there is a considerable variability in the nature" of sites along the Athabasca River within this corridor.

part two: Intervention

chapter five

Intervention

The Chapter is divided into two parts. In the first part, we discuss the principles that facilitate wetland viability and describe how these are undermined by the implementation of prescriptive sustainable strategies. Following this we propose 8 goals that will be used in developing a sustainable response for this site. Based on a synthesis of recent ecological research and practice, these 8 goals do not impose procedures or technical responses but rather, provide a conceptual framework for considering site details in relation to project targets, and thereby direct us toward developing an open-ended design response that reflects the site's unique ecological character.

In the second part of Chapter Five, these principles are documented in a series of diagrams. The diagrams depict the principles in use, and highlight the means by which a series of landscape interventions can be deployed in order to offset ecological damage and seed landscape processes that allow the site to heal itself.

The approach presented in this Chapter reflects the ideas presented in Part One of this thesis; namely, that landscapes exist as a network of complex processes and functions, and that local ecological processes are connected to operations being conducted across a series of scales simultaneously. As such, the interventions proposed in this Chapter reflect a direct understanding of the delicate and complex nature of the relationships that constitute the structure of the site and the processes occurring there, and accommodate these in order to ensure the site's ongoing viability.

ONE

The goal of this thesis is to develop a series of strategies for protecting wetland ecosystems from the ecological impact caused by urban development. It is based on the paired assumptions that ecosystems represent networks of linked processes that operate across both local and global scales, and that the ecological integrity of any ecosystem can only be maintained if the effects that impact one scale are controlled from adversely impacting processes occurring at another[1].

Since both urban development and daily urban activity drastically affect not only local ecologies but also the much broader systems with which these connect, this thesis proposes that any methods deployed to offset the negative effects of urban development can only be successful if they take into account the scalar nature of ecosystems and are deployed across both the local scale and, more significantly, the broader global scale[2].

What is at stake, of course, is the continued functioning of a globally scaled ecosystem, and the mitigation of any damage that would result from further urban development. Given the historically unparalleled volume of wetland destruction that has occurred globally over the last twenty years, the situation is dire[3] and methods for urbanizing wetlands in a more sustainable manner must be developed before continued over-development leads to irreversible ecological damage.

In previous Chapters we argued that because contemporary ecological research is demonstrating that many of the wetland restoration attempts of the past twenty years have fallen short of their goals, new approaches for sustainably developing wetlands might be developed if designers find methods for deploying non-prescriptive solutions within the landscape[4]. To that end, we propose that new approaches could be developed if designers begin to conceptualize restoration sites as networked systems consisting of processes and relationships that are cross-scalar both physically (across broad regions) and temporally (existing as processes functioning according to temporal patterns), if they recognize that these relationships do in fact constitute structural systems, and if they address the fact that each site is itself, simultaneously, a structural component within a broader ecological network.

The observations and conclusions derived in the previous four Chapters with regards to the structural delicacy and complexity of wetlands provide us with the means to begin outlining a basic approach to building within wetland landscapes. The conclusions outlined there illustrate that landscape processes and structure are scalar and adaptive, that structure is complex and delicate, that small changes within ecosystems can create massive disruptions within broader ecological frameworks, and that, in any case, the consequences of wetland disruption cannot be fully understood since structural relationships between wetland components are impossible to chart. Following from these conclusions it is a given that if we wish to develop wetlands we must, first and foremost, attempt to mitigate the amount of damage caused by construction and the presence of urban life, and we must find methods to deal with the structural damage caused by that development.

How then do we achieve these two ends; namely, to develop wetlands without inflicting structural damage, and to do so while simultaneously repairing the damage that such development inflicts, the latter issue, being the more significant one with regards to wetland viability over time since the ecological concern with regards to wetland development is not simply that development destroys ecosystem structure locally, but that by damaging structural it causes harm to connected networks and reduces the opportunity for future landscape regeneration.

The issue, then, is to find ways to mitigate the structural damage caused by urban development, to define strategies for simultaneously repairing structural damage so that the landscape is not crippled permanently but can regenerate over time, and to do so in the context of current ecological research that shows that many of the techniques deployed over the past two decades have not been successful.

Current research does not explicitly describe why prescriptive approaches to landscape remediation fail, but a survey of the available literature does seem to suggest that these approaches suffer from several shortcomings. In the first case, even though these projects attempt to mimic landscape structure, this new structure is not robust enough to withstand disruption, and the complex structural balances that define the original conditions are lost. Presumably, this may be a result of the fact that a) the relationships that those methods attempt to duplicate are too complex to reengineer[5], and b) because the structural duplicates found in those projects are not multi-scaled and seem to end at the limits of the site; that is to say, they do not pay attention to the fact that wetland structure is multi-scalar and requires multi-scaled connections in order to ensure its ongoing viability[6].

In the second case, the literature indicates that failed techniques seem to ignore the need to meet six conditions that are fundamental in ensuring wetland viability, namely;

- that since it is organization across scales that defines a wetlands degree of adaptability, wetlands require space beyond their borders in order to evolve[7];
- that seasonal patterns and cycles (such as seasonal flooding, for example) must continue to operate in order to the vibrant landscape conditions and wildlife relationships that define wetland heterogeneity[8];
- that wetlands are temporal entities, and that their structural relationships change and evolve over time[9];
- that wetlands need to be able to make territorially-scaled connections to other ecosystems across broad territories[10];
- that wetlands viability is dependant on their ability to adapt, and that they require both the space to allow this to occur, and

connections to other ecologies to which they can adapt[11]; and,

- that wetlands require connections to reserves of ecological capital found outside the limits of their own system[12].

Many ecologists describe depauperate wetlands as ones in which the opportunity to evolve according to these six conditions are limited or removed. I conclude from this that prescriptive approaches to landscape design fail specifically because they attempt to impose a final shape or outcome on the landscapes that they are remediating: that they both limit the ability of a wetland to adapt in ways implied by the six principles above, and that they fail to provide the necessary generative features that would allow those remediated landscapes to grow beyond the final outcome that they impose[13]. Such approaches, by both imposing a set of structural details on the landscape, and by attempting to prescribe a finished form, reduce the landscapes' ability to evolve according to the breadth of conditions implied by those six principles above. In other words, by imposing specific ends on a landscape intervention, and by defining that intervention in terms of details that can generate only one response (the prescribed final outcome), those interventions inherently limit the landscape's ability to grow according to the principles by which it would evolve in an unmediated state. Prescriptive approaches, then, limit landscape regeneration by failing to understand landscape processes on their own terms, and by applying a logic of growth and regeneration that does not match that of the landscape itself[14].

In other words, in those cases where landscape regeneration fails, that failure could be the result of the fact that those interventions failed to view landscape features as structural components; that they failed to view those structural components as relationship-based, and viewed them instead as singularities operating independently within the landscape; that the design solution imposed an outcome on the landscape; that they failed to design adequate flexibility into the solution; or, that they did not provide enough leeway to allow the landscape the opportunity to adapt according to its own logic. These interventions do not fail simply because they disrupt structural relationships or landscape processes, but because they impose conditions that limit the landscape's ability to evolve and adapt over time, and to generate new structural and unforeseeable relationships.

What these conclusions tell us is that any be approach must be "hands-off" since it seems that landscape craves options, and requires the need to choose its own level of freedom with regards to creating structural relationships, and determining the distances across which those relationships are defined.[15] Moreover, the response should be landscape-centric, one that eliminates to as great a degree as possible the imposition of static final outcomes, and that allows the landscape to recreate its own conditions, restimulate its own growth, and recreate its own links across scales and distances[16].

The strategy that is proposed below is one which must provide not only for local conditions, but must consider the protection of both local and large scale structural features, and must respond to the six principles stated above. It will not impose landscape features as a predetermined condition, nor as a result of a predetermining set of interventions, must not force a predetermined outcome by limiting intervention scope, details, or features so that only one outcome is attainable; must not remove extraneous details (or rather, must allow for and even foster, features that are non-essential); and, it must not attempt to recreate any features specifically, nor redesign landscape details that would generate specific and structural features.

In other words, this strategy will not recreate conditions, but will manage conditions that allow for possibility. Rather than imposing solutions and defining criteria, it will seed generative conditions that allow for multiple outcomes, rather than defining criteria. In this scenario, restoration becomes less a matter of putting solutions into place than creating a context that allows for the generation of relationships[17], less about rebuilding than about creating ecologically advantageous and activating conditions[18].

By now it should be clear that regardless of the steps taken to mitigate the ecological disruption caused by wetland development, such development will always inherently cause broadly scaled, unavoidable, and unpredictable damage. Moreover, because the boundaries between ecological systems are always porous, two systems in close contact will always affect influence upon each other[19].

This being the case, we must accept that no matter how landscape-centric our approach, the intervention will ultimately create a new ecosystem dynamic. Inevitably we cannot save the current landscape configuration. In fact, since the current dynamic is the manifestation of a series of unique predetermining characteristics (which will no longer exist), to restore and/or recreate that configuration is to ensure its eventual failure, since the final outcome will represent nothing more than the designer's assumptions about what he or she believes the appropriate state of that configuration should be[20].

That being the case, and given both that a) a meandering landscape system requires as a necessity of its ongoing and viable biodiversity the continuation of maximal exchange processes, ongoing system fragmentation and regeneration, and variable physical conditions to ensure species biodiversity and the continuation of ecosystem processes,[21] and given b) the near impossibility of recreating the structural features that define these delicate systems, we propose that whatever other steps might be taken to ensure the sustainable integration of one system into the other, that first and foremost the two systems must be treated as distinct, and that from the outset both systems must be separated to as great a degree as current technologies will allow us.

Thus, as a first step in our approach, we propose that new urban developments be built as islands within the surrounding landscape: distinct entities severed from any ecological connection with the surrounding landscape by a variety of landscape based interventions[22]. Once this is accomplished, we initiate a series of moves that are aimed at regenerating the viability of the surrounding systems. This will include, as a second step in the process, deploying a series of landscape interventions that will generate conditions that will foster the development of new structural relationships and new landscape processes within the landscape. We will, in other words, implement moves that will allow the landscape to begin to create a new marsh structure[23].

Following this, we propose a series of moves that facilitate the creation of broader territorially scaled connections, and foster the generation of processes and structure at that second scale. And finally, because boundaries between systems are too porous to imagine that there will be no unpremeditated overlap between the island landscape and the surrounding wetland (probably to detrimental effect[24]) we propose that a subsequent step would be buffer this overlap by determining specific loci of collision between the two systems, and implement buffer zones within these locations.

Following these four moves, every subsequent gesture will either reinforce the ongoing separation of the two systems, or create conditions that allow the landscape to remain viable by fostering (or "seeding") the development of new structural properties and relationships[25]. Specifically, we achieve these four ends by:

- identifying the components of the system at every scale[26] (in the case of this project, these include the riverbank, the river/riverbank threshold, the marsh, the wetland, the hyporheic zone, drawdown zones, and parafluvial ponds; the landscape type (bog, fen, or swamp); biotypes; landscape processes (providing shelter, filtering water, maintaining groundwater temperatures, etc; hydrological patterns, cycles and changes; and, site structure));
- identifying processes and creating a system hierarchy;
- determining where overlap exists between each scale;

- developing methods (architectural, infrastructural, natural, and/or assisted) for maintaining current processes;
- creating buffer zones between systems (to absorb ecological transitions between two states); and,
- improving site resilience by maximizing synergistic opportunities between the two systems (by identifying areas of potential overlap between existing processes and the urban development).

Though well intentioned, the above process describes yet another series of design moves that are structured in such a way that they generate a prescriptive response. The solution, as we have just outlined it, is not a strategy that can be deployed across sites, but rather, is an allotment of moves that generates a specific response in response a specific site. And whereas this solution may in fact work, our goal here is to define a principle that allows us to generate a broader response: one that does not outline steps, but that provides a principle that guides the development of a response (rather than prescribing one ahead of time), and one that, because of its lack of specificity, generates responses that are themselves open-ended and flexible.

One way to develop such a principle might be to take a step back from the goals as we have stated them – to integrate a system sustainably, to repair and mitigate the damage that such integration causes, and to do so by seeding generative conditions such that the landscape develops its own responses to ecological disruption – and to reformulate the design problem not as a set of defined solutions ("repair the damage", "seed generative conditions") but as a set of desired possibilities: best-case scenarios, overarching goals that could suggest possible outcomes without defining specific approaches[27].

These best-case scenarios could be summarized as a set of goals, targets that guide the design of any intervention and that represent the specific strategies which, if adhered to, allow for the sustainable development of any wetland site. Taken as a list of guiding principles – a set of goals toward which each solution should tend, rather than a list of outcomes – these goals could provide designers with a site-transferable framework for developing non-prescriptive and site-responsive solutions.

Conceptualized as such, the goals become a means for easing a desired outcome into place (rather than imposing a solution), and provide a flexible strategy for approaching the generation of technical specifics at each location where this design problem is encountered. And because the goals do not impose solutions but describe best-case scenarios, they become a means for fostering the interaction of conditions that are already present, for organizing generative conditions such that other forces develop their own solutions. The goals then, do not provide the designer with a prescribed solution – a list of specific outcome and target based solutions whose components can generate only one end, and in the event of a failure remain inactive and useless – but rather, a means by which to develop a framework that allows for the juxtaposition of generative conditions that will be organized into solutions by other forces, namely, the landscape itself.

The 8 design goals can be summarized as follows.

SEPARATE: in order to facilitate the ongoing viability of structural processes, and because these cannot always be identified, the two systems must be treated as distinct, and must be separated from the outset to as great a degree as technical means allow. In the case of this project, this is achieved by landscaping an urban berm within the wetland; a highly engineered island separated from the surrounding landscape processes using the same means that are currently used deployed in remediating toxic sites.

CONTAIN: because boundaries across ecosystem scales are porous, we must contain any potential source of ecological damage within the urban berm. Containment as a goal implies not just the separation of two incompatible systems, but a proactive attempt to retain any phenomenon that are likely to cross ecological boundaries. In our case, special attention must be paid to water and runoff. Containment is achieved by contouring the landscape, by deploying several layers of geotechnical membranes, by a system that contains and processes all berm runoff, and by a series of bio-filter buffers that ring the urban plan.

PROTECT: the surrounding landscape must be protected from the disruption brought about by the introduction of the new system into the landscape. Whereas "containment" implies implementing strategies to offset ecological damage from within the disruptive system, "protection" implies that strategies might be deployed within the damaged system to further guarantee system-island distinction and to create a barrier between itself and the new system. In the case of this project, several landscaping techniques and a series of buffer zones are deployed to protect the wetland ecosystem from the new development. As well, a series of unmanaged landscaped zones are set aside in the surrounding territory to ensure that source/sink relationships can be protected in the long-run.

These first three goals ensure that the two systems remain distinct and that the new system's potential to instigate damage (in addition to the one caused by its construction, of course) is strictly limited.

This second group of goals ensures that site structure and relationships between processes are protected, that the conditions that foster ecosystem growth are maintained, and that the structural properties of larger systems that may have been disrupted by development are also regenerated.

MAINTAIN: the structural elements that allow the wetland processes to function must be maintained. This is essential to the continued operation of landscape processes occurring across scales. To that end, local structure must be identified and their operations catalogued. With regards to this site specifically, those structural elements include (but are not limited to): the riparian zone, the cycle of periodic seasonal flooding that flushes the wetland; subsurface connections between ground water flows; parafluvial ponds; deposition plains; bank stability and pressure; drawdown curves, and the trophic linkages and biological relationships that occur above and below the water's edge along the riverbank[28].

OFFSET: the damage created by construction and by the presence of the new system must be offset, either by deploying strategies that regenerate previously existing conditions, or, when damage as a result of new development is too great that regenerating those conditions is an impossibility, deploying strategies that limit functional stresses at the affected location. In our case, methods are put in place along the riverbank to enhance the potential for seasonal flooding.

REPLACE: in some cases, damaged processes and conditions can be recreated or replaced. Typically this will be achieved by seeding new structural relationships and processes within the landscape (as opposed to simply recreating previously observed (and potentially misunderstood) conditions). In the case of this project, riverbank conditions adjacent to the riparian zone are replaced using a number of seeding techniques.

If the previous six goals described the means to regenerate baseline local conditions, then the final goals introduce the possibility of enhancing ecosystem behaviour by locating and generating potential means of synergy between the two incompatible systems.

AUGMENT: if urban development is carried out successfully, landscape processes occurring within new system can now to be linked back to the wetland. In these cases, augmentation of local conditions by (unmanaged) engineered processes will enhance both the operation of site functions and processes as well as the overall viability of the local ecosystem. In our proposal, captured floodwaters and urban runoff are processed in a series of naturalized holding areas and wastewater bio-filters, to be eventually drained back to surrounding wetlands This flushing ensures the health and growth of a wetland that has been disconnected from a water source, repopulates the wetland with organic matter, and ensures viability during drier seasons.

CONNECT: the seven previous goals could not protect the surrounding system if, finally, care was not given to maintaining the structural and systemic links between processes occurring across scales. It is not enough to assume that local protection will ensure wetland health, and sustainable integration cannot be limited to interventions whose reach extends only to the limits of the site. As we have discussed, wetlands require space in order to evolve, and new sources of ecological capital and in order to adapt and grow. In the case of this project, the opportunity for such growth is provided in the form of ecological stepping stones ; protected sites dispersed across the landscape that form a mosaic that might allow wetlands to generate connections to a chain of broadly dispersed, ecologically diverse protected landscapes within the watershed.

The 8 goals do not prescribe a set of outcomes, nor define the means for achieving a set of targets. Instead they create a context in which site-specific, open-ended, generative responses can be developed. The goals do not prescribe solutions; they mediate between a state of ongoing damage and a state from which growth can be generated. Rather than prescribing the end result of this growth, and outlining an approach for achieving an end that can be quantified or defined, they clear a space in order to allow that damage to occur, and propose a framework for setting up conditions that privilege landscape operations within that damaged condition.

TWO

Ultimately, this thesis proposes that new urban development be constructed discrete from the surrounding landscape but connected to several key processes at specifically selected locations, such that together they form an augmented system that maintains the properties of the initial ecology. Combining these construction strategies with a series of landscape interventions that seed new landscape processes in the surrounding region, the intervention initiates a series of generative processes that allow the landscape to begin to create sets of conditions that will allow the it to heal itself.

Because urban development inherently requires the destruction of portions of an ecosystem, because ecosystems operate as networks, and because destruction of a portion of a process invariably affects the functioning of the whole system, the interventions must be deployed both locally and across ecological scales (thereby fostering growth of connections at the broader territorial level). Only then can the intervention offset the global systemic effects of urban development and maintain the ecological integrity of the system.

The strategies proposed by the 8 goals are implemented in this thesis as a series of landscape interventions implemented across three scales.

At the local intra-urban scale, these moves include: creating an urban island within the landscape; contouring the landscape in order to control runoff and direct it to a series bio-urban remediation filters; creating a zone of naturalized buffer landscapes that ring the town and mediate the overlap between the two systems.

At the local landscape scale these moves include a series of operations conducted along the riverbank, along the riparian boundary between the urban berm and the river, along the hybrid buffer zone, and each one attempts to reinforce structural connections and set in motion processes that will generate new structural relationships. Specifically these moves include (more will be described in the diagrams below) mediating conditions at the urban berm/riparian threshold in order to maintain a distinct separation between the two systems; creating flood inlets to allow riverwater access to the site and maintain patterns of annual flooding; grading and spiking the riparian edge in order to facilitate the regrowth of the riverbank; and creating soft riverbank edges to facilitate the growth of parafluvial ponds and new hyporheic zones in the structural zone adjacent to the river.

At the meso-scale interventions are deployed in order to protect and maintain local processes and structure, as well as providing a series of site specific interventions for maintaining the integrity of the local system. Specifically these moves include: the setting aside of landscape zones to act as structural corridors, and thus, seeding new local connections between disconnected landscape patches; and seeding a number of connections between the urban island, its surrounding mediated buffer zone (the perimeter marshes) and the local landscape in order to foster the development of a hybrid zone adjacent to the urban edge (one which will protect the boundaries of the wetland from future disruption).

Finally, at the large regional and territorial scales the strategies implemented include creating protected and managed ecologies that act as structure for the growth and maintenance of large scale ecosystems, and that shore up the strength and vitality of those large scale ecologies; seeding wetland islands within the landscape in order to create ecosystem stepping stones that foster the growth of the wetland into new territories (or not); and setting aside ecological corridors in order to ensure that large scale ecological processes are linked, or have at their disposal the option to create links in the future.

At each scale the intervention reinforces one or several of the 8 primary design goals. Each move also reinforces the landscape requirements described above (that landscape is scalar, that it requires the opportunity to make broad territorial connections, that it requires space to adapt, and that it requires connections to alternate sources of ecological capital). Taken as a suite, this blanket of interventions creates an instrumental landscape; a layered series of active and activating earthwork interventions operating across scales to create generative processes that allow the landscape to heal itself.

The Intervention Diagrams

The following diagrams represent the strategy developed in this theses, and are based upon the principles and goals discussed above, namely, to separate, contain, protect, maintain, offset, replace, augment, and connect.

Taken as a suite, the diagrams represent the site strategy that would need to be implemented across the three landscape scales in order to achieve the sustainable integration of an urban development within a functioning wetland context.

The following diagrams highlight the manner in which the 8 principles discussed above take shape within the landscape; namely:

i. by ensuring the separation of non-integrating systemic processes (namely, of the landscape and the urban development) by creating a distinct urban island within a wetland site;

ii. by controlling the overlap between distinct processes (namely, that of the urban development with the surrounding landscape) by creating a manageable set of urban processes within a managed environment (by engineering an urban berm that would separate urban processes from those of the landscape and allowing only negotiated and managed interaction between these two systems), and by implementing a series of local measures for ensuring the protection of water (which moves fluidly between systems);

ii. by offsetting damage to local structural hydrology and thereby ensuring connectivity between structural elements and processes (by seeding new connections between aquatic and landscape thresholds[29], and by generating new landscape processes between the urban development and the landscape proper), and by creating conditions that would allow for the regeneration of these processes in the event of disruption (by creating a seeded riverbank riparian edge); and,

iv. by creating reserved and managed landscapes (at the river's edge, within the midscaled adjacent territory, and at the broad watershed scale (larger reserves), as well as,

v. migrating the marsh and creating a "back-up" landscape reserve within the larger territory (by seeding the growth of green corridors into the broader territory).

Taken as a pair, the final two actions ensure the ongoing viability of the surrounding wetlands, provide a space for the ongoing development of new landscape processes within the greater territory, and allow wetland processes to create new connections across a now disrupted landscape field. Rather than representing a prescriptive method for achieving this end, the principles described below allow the local ecosystem to achieve these goals according to the logic of the landscape itself.

The following diagrams document the deployment of the strategies developed above across a number of scales, and illustrate the means by which those strategies are implemented as landscape interventions. The first three diagrams provide an understanding of the key moves occurring at each of the three scales. The sections that follow illustrate the operation of the intervention at key locations.

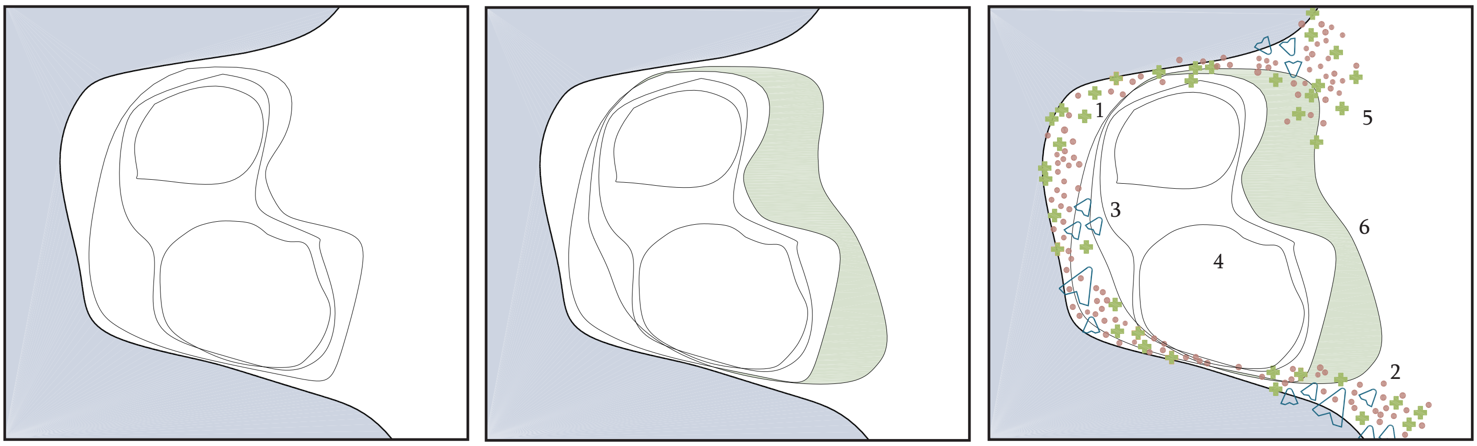


diagram one:
Landscape Interventions at the Local Scale

The goals of the interventions carried out at the local scale include: 1. successfully separating the new urban island from the surrounding landscape and containing any potential damages that it could inflict upon the surrounding landscape; 2. to foster the regeneration of local wetland structure at the local scale; 3. to protect that structure to ensure its viable growth in the short term; 4. to mediate the buffer relationship that will inevitably develop between the limits of the urban island and the landscape; and, 5. to target potential areas of overlap between the urban island and the surround landscape and insinuate new (mediated) connections between the two in cases where such connections would mutually benefit either or both of the systems.

Diagram 1 highlights the intervention methods deployed for protecting and maintaining local processes and structure, as well as providing a series of site specific interventions for maintaining the integrity of the local system.

The diagram illustrates the means by which we create the urban island and protect the surrounding wetland. The order of construction includes: creating a partition; raising a new set of contours (in this case the double-peaked ring on the site's western edge); creating a deposition field (shown as brown dots) where the field is graded and spiked to allow for seeding by plants and soil). This seeding allows for the regeneration of a riparian edge and the regeneration of braid bars and parafluvial ponds); subsequent development of riparian edge; building the town campus (on top of the berm); removing the partition; and allowing natural succession to create a link between the hybrid buffer (shown in green hatch) and the surrounding landscape (i.e.: merging the buffer and the landscape).

For every town constructed upon the buffer berm, the following order of construction is adhered to: reserving land to create a riparian buffer; priming the sedimentary deposition plain; creating an urban runoff network (composed of SUDS (sustainable urban drainage), bioswales to direct runoff, local pools to collect runoff, a channel network to divert the runoff to local holding ponds and the urban runoff marshes)); creating they hybrid buffer; and generating connections (both engineered and natural) between the buffer zone and the surrounding landscape.

With regards to wetland regeneration at the local scale, the order of operations is as follows: the riparian buffer is reserved and the deposition plain is prepared; the hybrid marsh network is connected (see 2 above) to the local marsh structure (parafluvial ponds, drawdown zones etc); a series of protected marsh localities is set aside within the landscape, as are connective corridors linking these. This series of links will, with time, create a new corridor of connected green wetlands (the green necklace) and ensure the protection and regeneration of the riparian buffer at the water's edge, and ensure that disparate wetland pods within the landscape maintain ongoing connections.

Diagram One highlights:
1. the protected riparian zone; 2. the seeded riparian buffer zone, 3.seeded inflow channels; 4. the urban berm; 5. seeded ponding areas; and, 6. the hybrid buffer zone. A typical town plan would be located on the berm proper. It's characteristics are described in Diagram Two below (as are those of the hybrid buffer).

The Seeded Riparian Buffer Zone (2): As per the site strategy developed in this thesis, the riparian buffer is not "reconstructed" but prepared for natural succession. Landscape is roughened, and natural construction waste is dumped along buffer.

The Seeded Inflow Channels (3): Inlets engineered into the seeded zone at progressive intervals along riverbank. With time these "seeded inlets" will accelerate flooding patterns at specific locations, and allow water access to the a) hybrid buffer zone, and b) the marsh interior, thereby maintaining seasonal flooding patterns. The Seeded Inflow Inlets create strong connections to interior marshes east of the Urban Berm.

The Landscaped Berm (4): The "buffer berm" upon which the town campus sits.

Seeded Ponding Areas (5): Landscaped depressions intended to hasten development of ponding along riparian edge (and thus re-development of marsh conditions along riparian buffer)

The Hybrid Buffer Zone (6): A naturalized marsh buffer creating a plateaued separation between the town campus and landscape adjacent (it sits on the landscaped Buffer Berm). Acts as a collecting sink for urban runoff (post treatment) and a protective strip between landscape and town campus.

CITATIONS
Misc: Karaus, Alder, & Tockner (2005); Tockner, Paetzold, Karaus, Claret & Zettel (2004).
On Seeding: Davies-Colley (2000) ; Fischer, Ricard, Martin & Fischenich (2000); Hanowski, Wolter & Niemi (2000), Murgatroyd (1983); Gray & MacDonald (1989); Rowntree (1999).
On Seeding Braid Bars: May & Horner (2000); Hagerman & Williams (2000).
On Island Formation: Gruntfest (1991); Nieswand, Chavooshian, Hordon, Shelton, Blarr, Brodeur & Reed (1989).
On Scalar Boundaries: Allan & Hoekstra (1987).

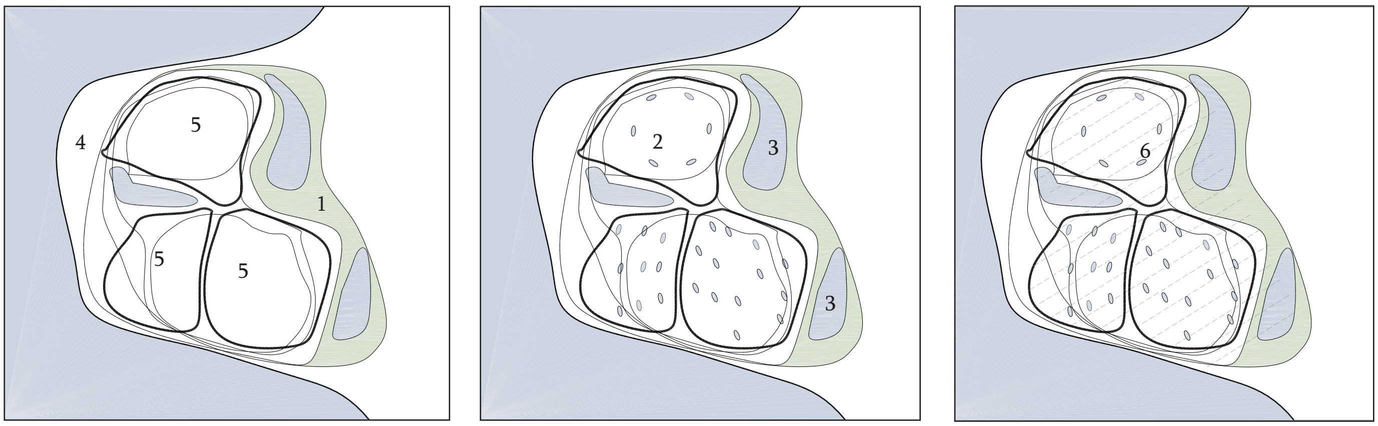


diagram two:
Landscape Interventions at the Mesoscale

The goal of the interventions carried out at the middle scale is to successfully begin to regenerate marsh structure, and facilitate the growth of a larger marsh network at the broader scale.

Diagram highlights the intervention methods deployed for protecting and maintaining local processes and structure, as well as providing a series of site specific interventions for maintaining the integrity of the local system.

To that end: the diagram illustrates the development of features that will lead to the migration of marsh structure (from the zone now inhabited by the urban development); the setting aside of landscape zones to act as structural corridors, and thus, the seeding of new local connections between disconnected landscape patches (and thus, the seeding of a new green necklace and the laying down of the roots new marsh structure); and the formation of mid-scale connections between the urban island, its surrounding mediated buffer zone (the perimeter marshes) and the local landscape.

A note with regard to water: in order to protect the surrounding landscape from the flow of urban runoff, three measures of control are instituted at this level to deal with water. With regard to water, we must put in place measures to deal with four issues of concern; namely: urban run-off; floodwater (as it flows into and then back out of the urban island); local greywater, and the continuation of seasonal flooding patterns. The measures put in place to deal with these manifestations include the Urban Berm, the Urban Bio-Filters, and the Hybrid Buffer. These mechanisms create a system to divert runoff from paved streets and rooftops. Bio-swales and landscape contouring are both used to divert runoff to collecting pools (naturalized bio-filter marshes), and eventually, to the urban bio-filters. Here the water is remediated and released back into the on-berm groundwater system. As depicted on Diagram 2, subterranean channels collect this water and over time it is slowly released back into the landscape (as part of the augmented seasonal flushing that occurs at the site).

Diagram Two: Mid-Scaled Elements highlights
the relationshp between the buffer marshes (large scale naturalized holding ponds within runoff channel/Urban Bio-Filter system) (3), the urban filters (local greywater and runoff filtering systems) (2); the hybrid buffer zone (1); the seeded riparian zone (4), and local neighbourhoods (5), as well as indicating the location and arrangement of the subsurface water network (6).

The Urban Filters (2) facilitate augmented seasonal wetland flushing.

The Seeded Riparian Zone (4) facilitates ponding, marsh growth, riparian health, braiding, and riverbank stability, and highlighting the relationship between the marsh interior and riverbank marshes north and south of the proposed town campus.

The Network Of Landscaped Runoff And Drainage Channels (not shown, but running between the urban filters) treat runoff, drainage, and grey water before purging it to the hybrid buffer zone (ensuring runoff does not pollute the marsh directly).

The Urban Filters (2) are found throughout the town. Their position is randomized according to neighbourhood orientation (grid, suburb communal, semi-private, gates, trailer, etc) and the to which the channels are integrated into daily life. They can remain hidden, or become a focus for the community. The network eventually processes all water entering the berm, and is connected to each stage of the water control, delivery and management mechanism on the site.

Arranged on a grid, the Subsurface Water Network (6) allows for any configuration of urban filters, urban channels, and community types organized around these landscaped features.

The design of the town plan proper falls outside of the scope of this project, given that much of what we are developing preceedes the actual construction of any town. Which is to say, as long as the town plan is sustainable, any town configuration is possible within the urban berm. The configuration shown above in Diagram Two hints at a three node community, encircled by a ring road configuration, or major axes. Any configuration is, of course, possible.

CITATIONS
Misc: Zhang (2005); North Carolina State University Water Quality Group (2005, 2006-1); Pietroniro & Demuth (2006).
On Making Mid-Scaled Connections & Adaptability Of Bank Conditions On Meander Rivers: Hagerman & Williams (2000).
On Braid Bar Migration: Lee, Hyung & Yong (2006).

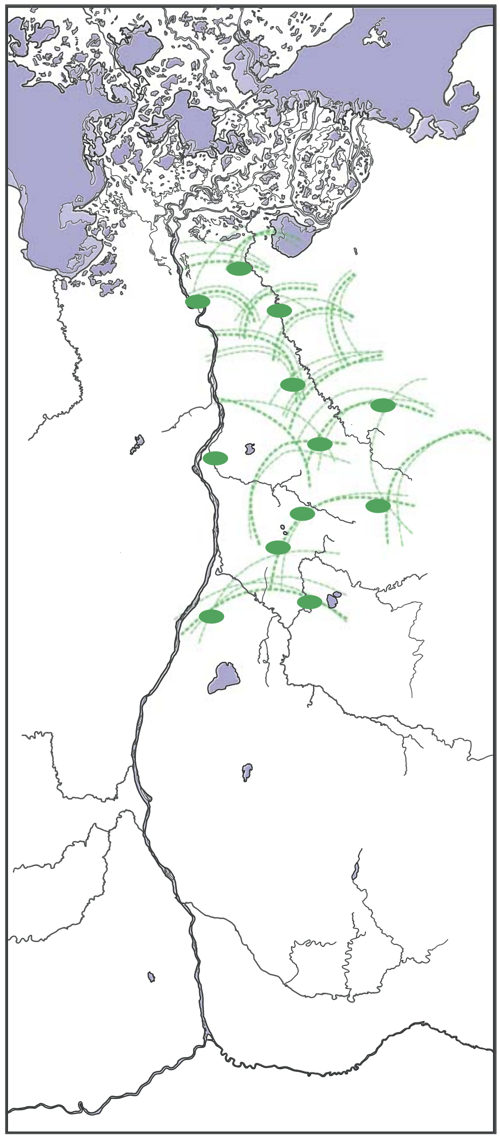


diagram three:
Regional and Territorial Scales - Extra-Urban Landscape Interventions

The goal of the interventions carried out at the territorial scale is to ensure the wetland's ongoing viability by allowing it the opportunity to connect to disparate ecosystems, sources of reserve ecological capital, and alternate sites for future regeneration. In keeping with the landscape principles described above (that landscape is scalar, that it requires the opportunity to make broad territorial connections, that it requires space to adapt, and that it requires connections to alternate sources of ecological capital), the moves carried out at this scale ensure that such conditions are maintained, and thus, ensure the ongoing viability of the ecosystem beyond the scale of the site.

Diagram Three highlights the intervention methods deployed for protecting and maintaining local processes and structure, as well as providing a series of site specific interventions for maintaining the integrity of the local system.

Diagram Three depicts a network of protected landscape zones. The landscapes are selected according to features that would best generate optimum conditions for growth for an expanding wetland. In this case the arcs reflect the local topography; water flows downhill from the Alberta Plateau, and generative conditions are more likely to be encountered within the range of those flows.

Within this network, two means are used to ensure ongoing wetland growth:

1. The Protected Wetland Ecological Reserve Territories (shown as green orbs): As per thesis strategy, these reserved zones ensure habitat and population renewal, the connection of newly developing wetlands to capital rich ecologies, and the development of wetland and/or green corridors according to the logic of the site.
2. Protected Proposed Green Corridors (or strips): As per thesis strategy, these corridors ensure habitat renewal, marsh resilience, connection of newly developing wetlands to capital rich ecologies, and the development of wetland and/or green corridors according to the logic of the site itself.

It should probably be noted that the site is already operating as part of a a link in a wetland chain. As a location where silt is deposited, this site acts as the first step in a succession landscape. Also, because water is able to penetrate the site, the wetlands on the east bank of the River are gauranteed renewal.

At a broader scale, the meander creates a periodicity, a rhythm of change and renewal within the evolution of local ecologies. Because the river meanders with time, local habitats are flooded or regenerated as water recedes or floods local sites. The moves carried out at the territorial scale ensure that these rhythms and patterns continue.

CITATIONS
On Migrating Structure: Westerberg & Wennergren (2007); Fischer, Richard, Martin & Fischenich 2006; Gruntfest (1991).
On Maintaining Links to Ecological Capital: Tittler (2006); Tockner, Paetzold, Karaus, Claret & Zettel (2004); Lier (2002); Hanski (1999); Roberts (1998); Dias (1996); Howe, Davis & Mosca (1991).
On Creating Connections Across Scales: Tittler, Fahrig & Villard (2006); Pahl-Wostl (1998); Moldan (1994).
On Ecological Stepping-Stones: Lier (2002).

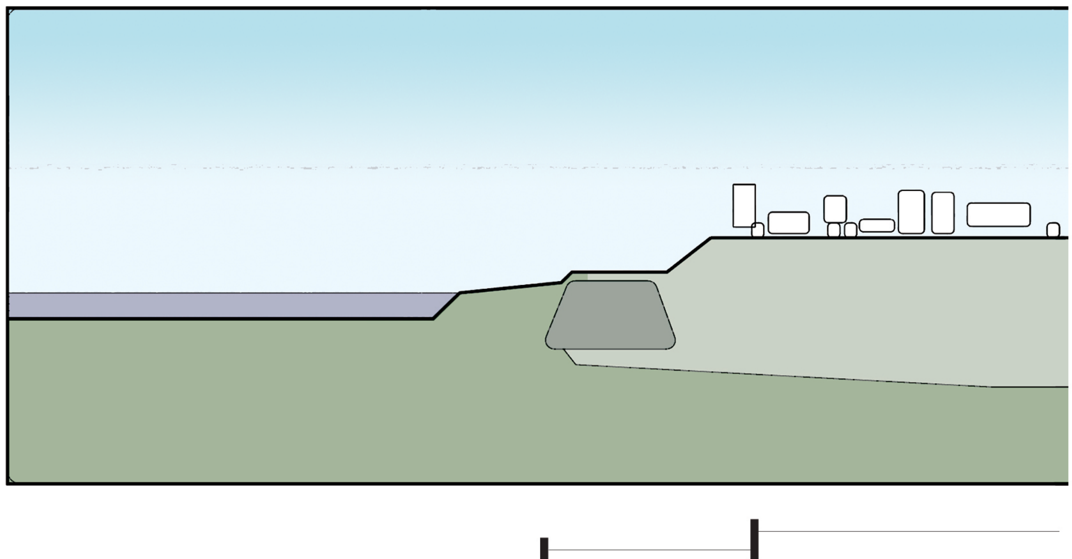
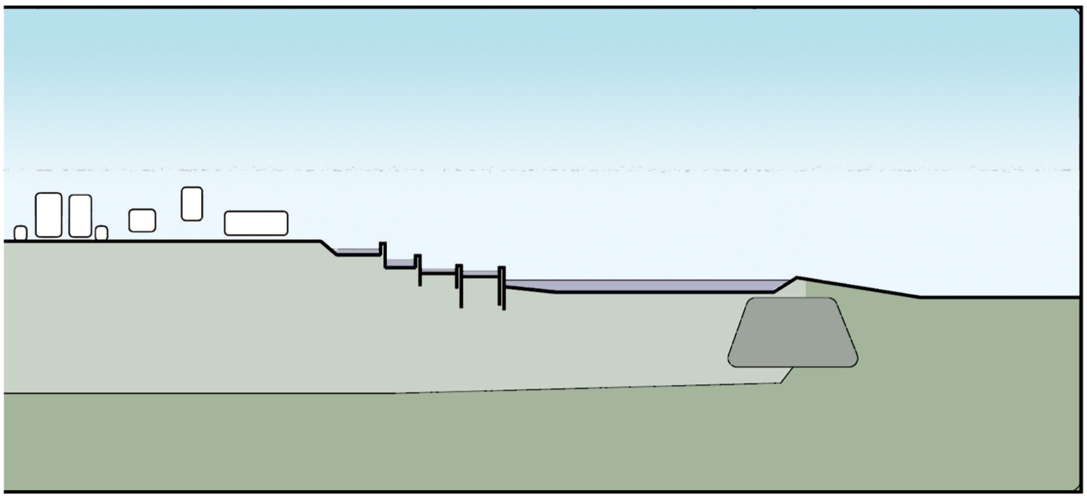


diagram four:
Urban Section Diagram One

The diagram shown above illustrates the section as a partis and describes in one glance the components of the urban berm. It acts as a key diagram to the more detailed section that follows below.



Geotextiles separate the berm from surrounding landscape, and ensure no pollutants filter from the berm and back into the marsh, the riparian zone, or the River.

The Urban Buffer: a ring of naturalized wetlands that border the town campus occupying a space between the city and the wetland (and/or the hybrid zones). The Hybrid Buffer Zone offers the surrounding wetlands a second layer of protection from the city. Stormwater and run-off are collected and processed within this zone in collecting pools and urban biofilters.

The Hybrid Zone: lies between the buffer and the wetland proper. The landscape here is neither managed nor tended, and no clear distinction exists between itself, the urban biofilters, and the surrounding wetland. It is the one location where the two systems converge. Over time, the hybrid zone will either: return fully to nature; provide a greenbelt should the city grow to engulf it, and/or; provide the wetland with one more layer of ecological security.

Wetland

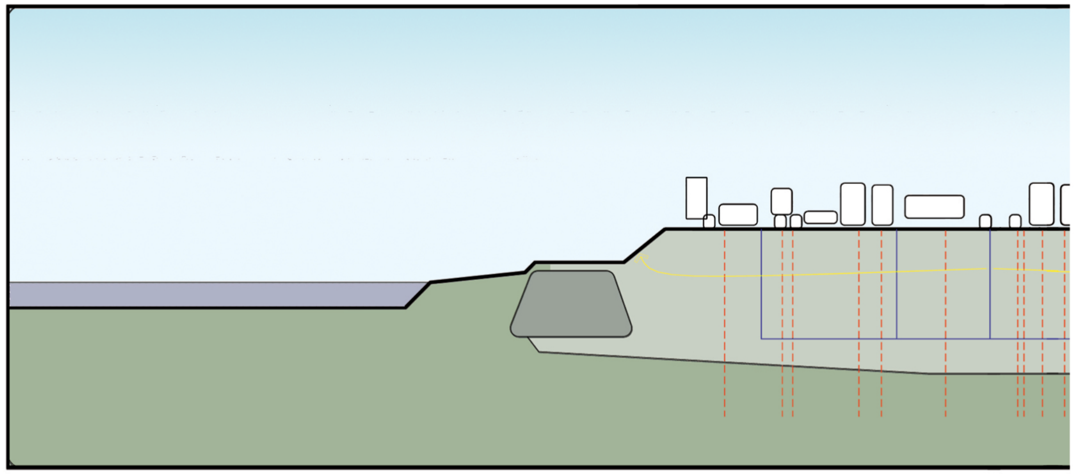
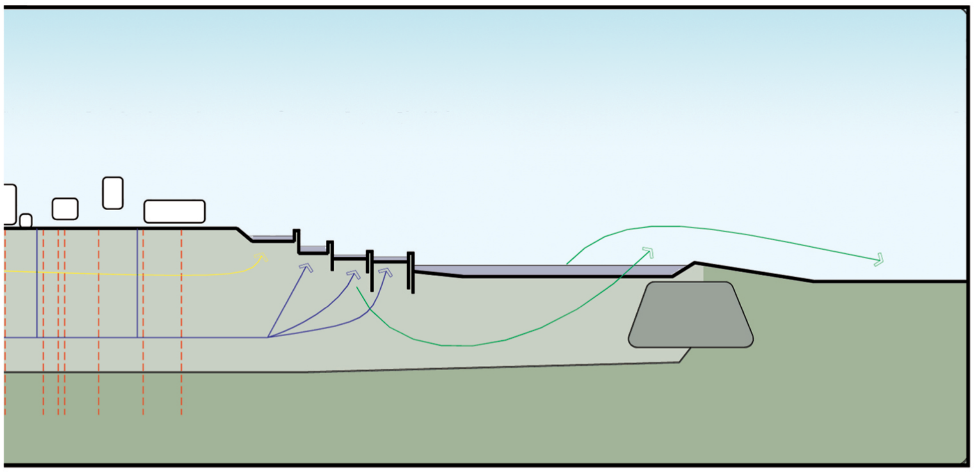


diagram five:
Diagrammatic SectionNumber Two

This diagram illustrates the ways in which the urban berm meditates between the landscape and the town, and the ways in which the berm is designed to prevent run-off from polluting the surrounding landscape.

1. Geothermal wells (orange dotted lines) are used to take advantage of the site's unique hydrological properties and provide deep water cooling in hot summer months, and geothermal heating in the winter.

2. Hydrological landscaping in the form of contours and berms collect and direct runoff, moving it toward a series of catchment channels from which it is eventually pumped via a subsurface network (blue arrows) to both small-scale community bio-filters located in each neighbourhood, and larger urban-scaled filters within urban public



spaces. Within these bio-filters water is processed naturally before being recycled and pumped back into the city's grey water system, for use in irrigation, urban maintenance, and industry. The waste-water from this process is collected and returns to the loop to be filtered once again.

3. Water that escapes the urban channel system makes its way back into the berm. Because the berm is separated from the surrounding landscape with a series of geotextiles, water within this landscape can be easily captured via drains and pumps and be diverted back into the greywater filtering sytem (yellow arrows).

4. Filtered water from the bio-urban filters is usually recycled back into the urban grey water system, or used for irrigation and maintenance. At periodic intervals, water from the filters is used to flush the hybrid zone (green arrows), and/or pumped directly into the surrounding landscape, thereby augmenting groundwater renewal and enriching the wetland with nutrient rich water.

diagram six:
The Large Urban Section

The following diagram illustrates the manner in which the separation of the urban system and the surrounding landscape is achieved, as well as illustrating the seeding of a new riparian buffer, new marsh structure as a function of growth adjacent to the inlet channels, new drawdown zones, and till-collection boundaries.

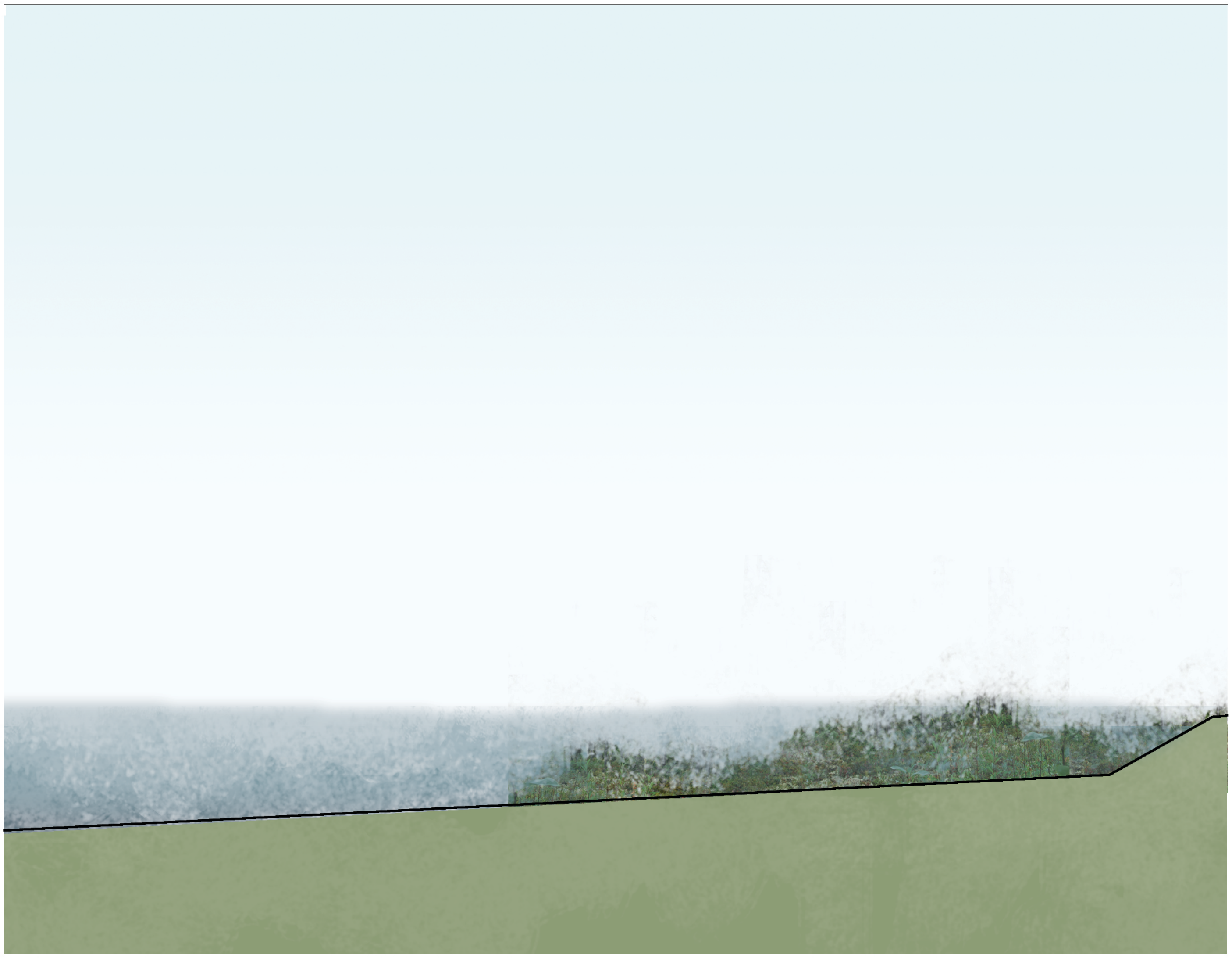
Engineered in keeping with those techniques that are used in toxic remediation projects, the details deployed here ensure as distinct and total a separation of the two systems as we are able to achieve at the present time. The remaining information depicts the order in which the new structural system is seeded; specifically it depicts the preparation of a riverbank seeded to generate a new shoreline. To do so, a soft edge is developed to facilitate the growth of these parafluvial ponds and hyporheic zones along the riverbank. This shallow edge allows flooding and invites the development of refugia. By creating a sizable gap between the new intra-marsh inlets and the new built-up berms, those soft edges are given the space and leeway to develop without following prescribed conditions. As distance from the urban island increases, less managing and manicuring of the landscape takes place, such that the degree of potential reconfiguration increases as you move towards the water's edge. Adjacent to the river's edge the bank is graded and made rough with compostable construction debris (to encourage the development of new plantlife, and to kickstart the process of natural succession). The absence of a sculpted edge along the river encourages the development of naturalized trophic linkages at the riverbank.

Diagram Six illustrates a number of functional attributes of the urban berm. It describe the intervention in great detail at three key locations: at the riparian/seeded riverbank edge, and depicts riparian buffer details, engineered marsh structure, and new drawdown areas; at a connection point between a runoff channel and an urban biofilter; and, at the transition point between the urban edge, the hybrid marsh edge, and the landscape edge.

This diagram describes process for ensuring bank stability, bank processes, riparian buffering, riparian and bank viability, trophic linkages (both horizontal and vertical), and wetland/river relationships. It describes the method by which the seeded zones are, in fact, seeded. It depicts the urban berm as it makes contact with the riverbank edge, the engineered riparian buffer structure leading into river, and the graded and seeded riparian plateau. Most of the technical details contained on this diagram are borrowed from typical toxic remediation sections (i.e.: those constructions where a distinct and total separation of natural landscape and toxic/remediated site must be maintained).

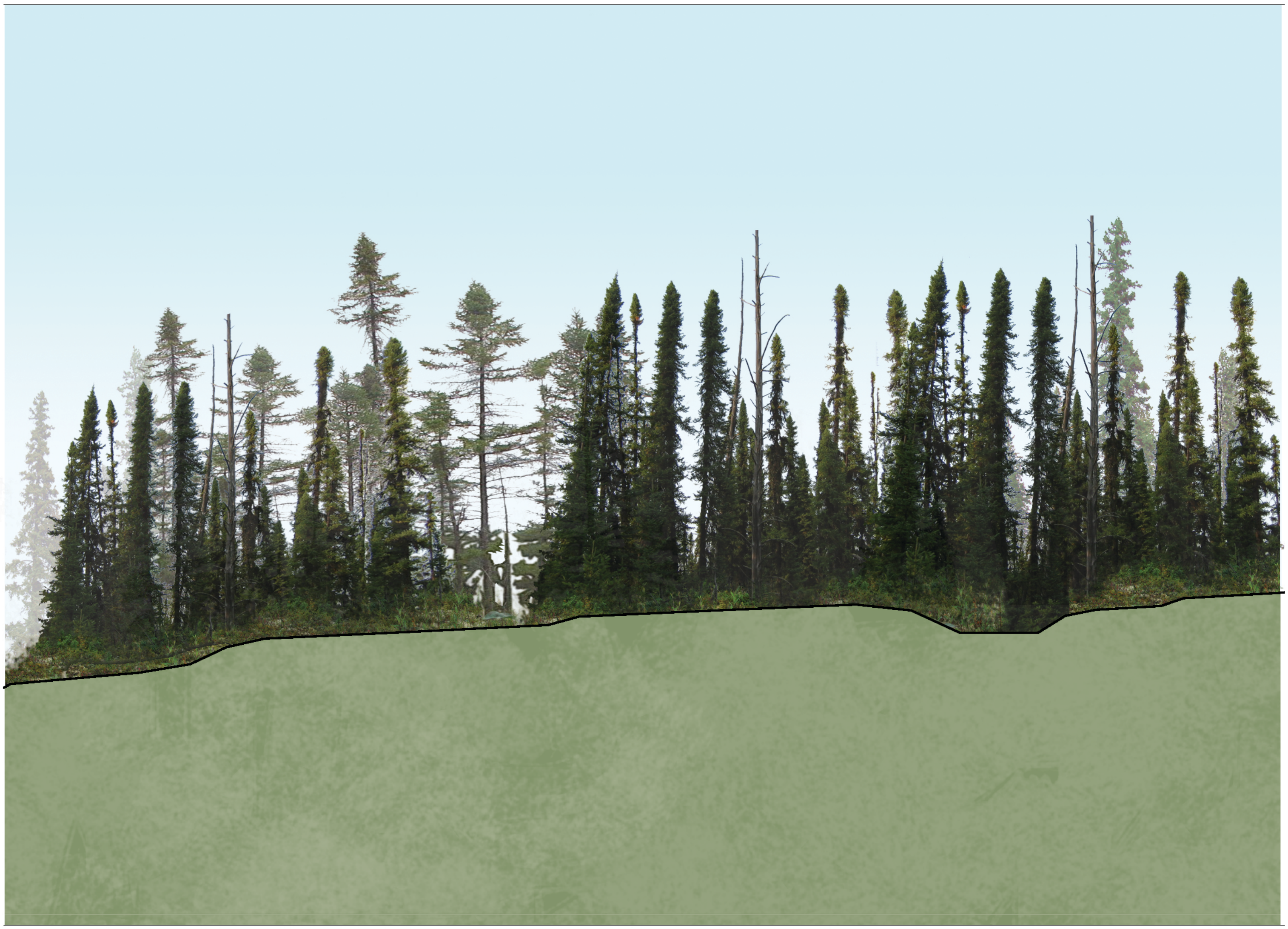
If previous diagrams illustrated the layering of engineered landscape elements at three different scales, then this diagram illustrates the urban components of such a landscape. Taken as a whole, as a connected system of engineered plateaus, these layers describe what I refer to as the Instrumental Landscape: the engineered landscape that provides a mediating device between landscape and urban processes, and which allows development of the landscape precisely because it both separates the two distinct processes, and because when it does allow for functional relationships, it does so in a mediated manner.

CITATIONS
Misc: Karaus, Alder & Tockner (2005); Conly, Crosley & Headley (2002).
On Banks, Bank Stability, & Hydrological Pressure: Nanson & Hickin (1986); Murgatroyd & Ternan (1983); Patrick (1973).
On Complex Surface/Subsurface Relationships: Clinton & Edwards (2000).
On Complex Trophic Linkages: Magilligan, Nislow & Salant (2004); Tockner, Paetzold, Karaus, Claret & Zettel (2004); Ward (1989).
On Local Hydrology: Lee, Cheryl & Boutin (2004).



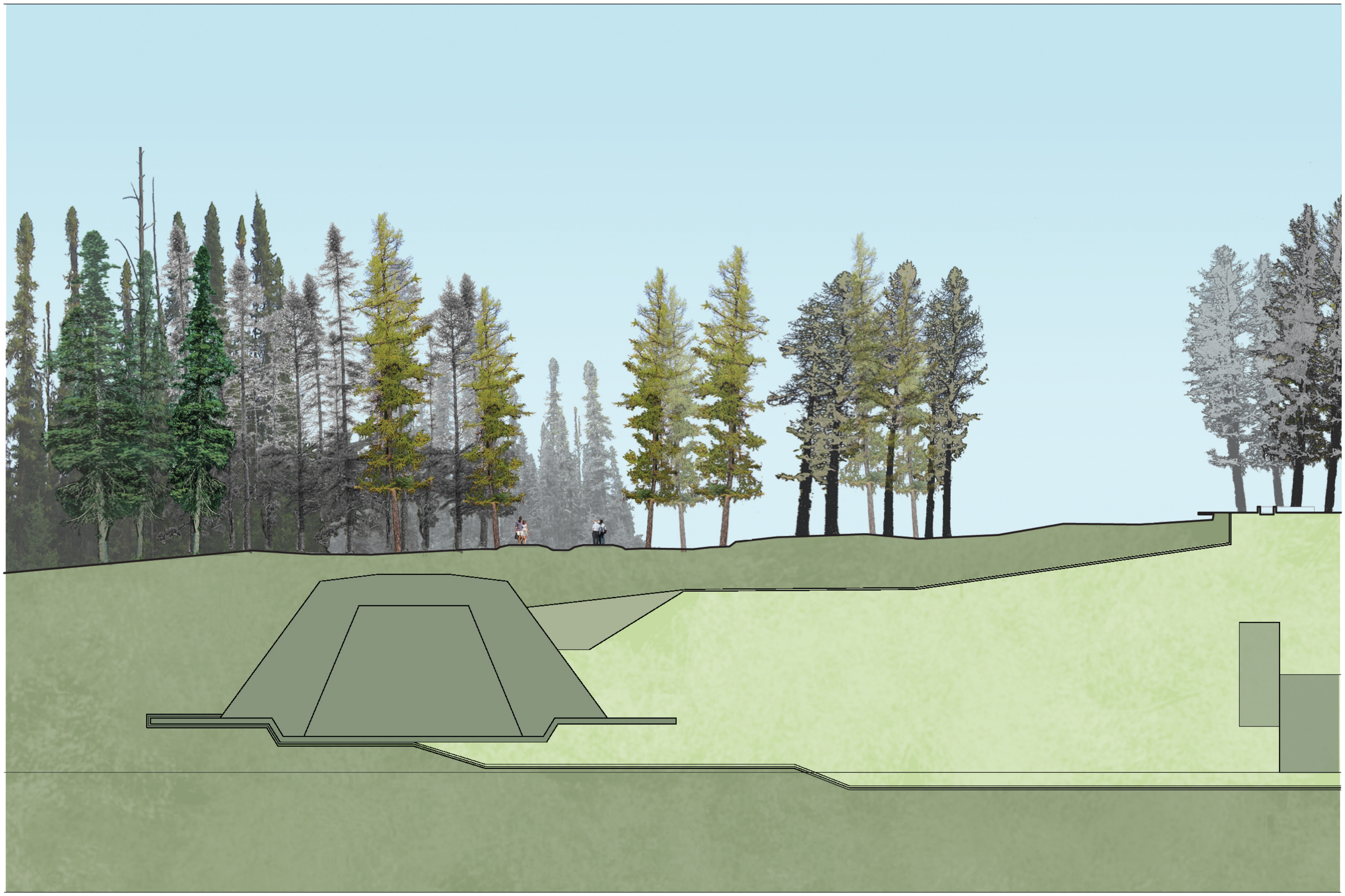
Adjacent to the river we find the seeded riparian zone. A band of protected landscape measuring at least sixty metres, the seeded riparian zone is not reconstructed to mimic the previous landscape, but rather, prepared in such a way that it can grow back into a naturalized state.

To that end, the riparian zone is reconstituted and several strategies are used to foster growth at this edge. The landscape is roughened, pitted, and graded to accept new seeds and plantlife. Organic waste material (landscape landfill) gathered during the construction of the berm is dumped along buffer and large scale fill (rocks and construction rubble) are dumped along the shore. Over time, the landscape will regenerate as new plantlife finds a home there, and the river reclaims and redefines the edge condition.



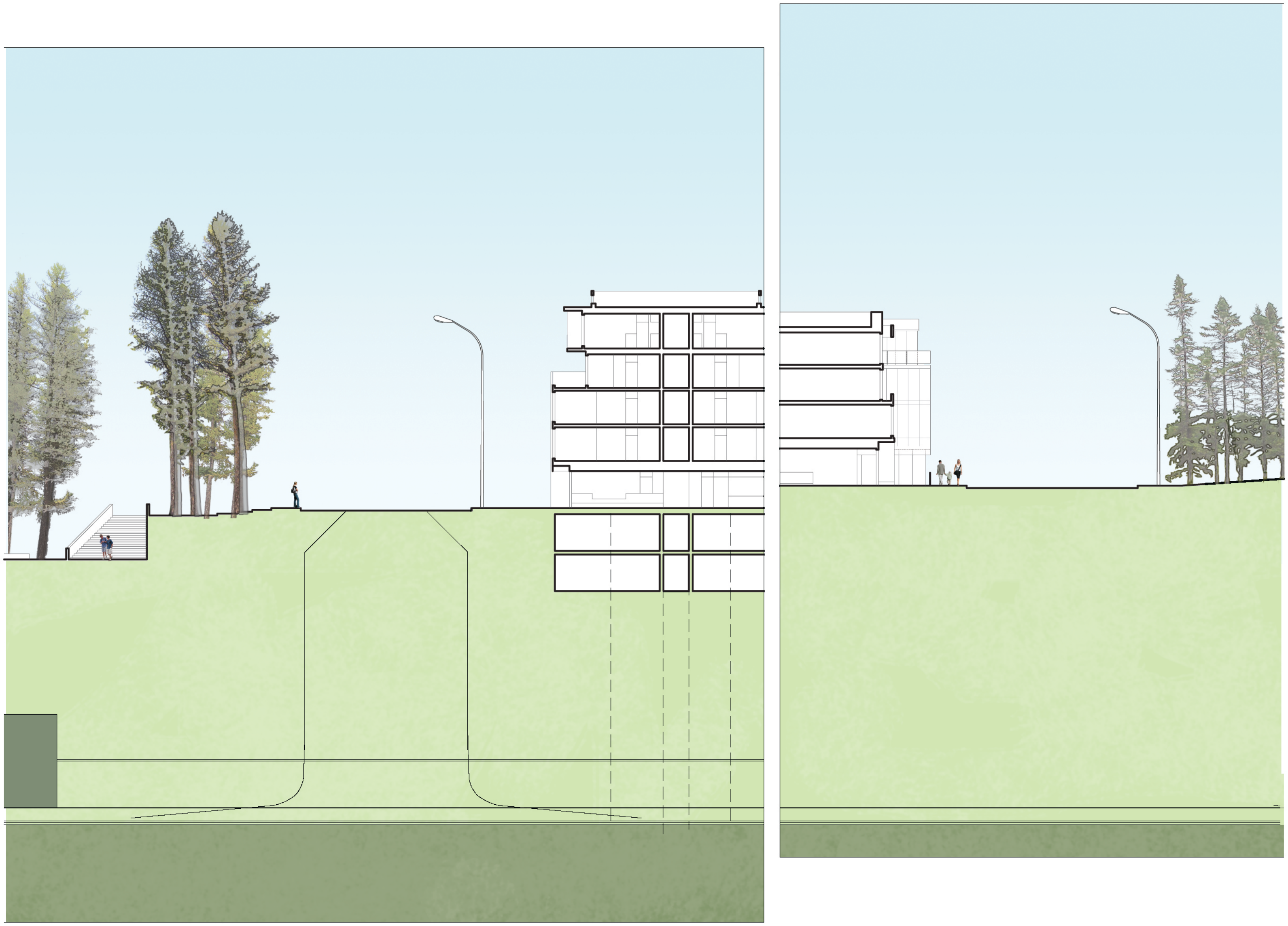
Moreover, the riparian zone is seeded to facilitate ponding and braiding in order to foster the growth of wetland structural features. Shallow riverbanks allow localized overflowing along the edge condition and promote increased biodiversity by reconstituting vertical and lateral trophic linkages. Flooding also promotes sediment deposition that leads to plant growth. Engineered inlet channels (as described in Diagram One) allow flood waters regulated deep access onto the wetland (as controled by bank slope and depth) which promotes refugia and allows for regeneration of the riparian edge.

This drawing shows a narrow edge condition; the long steep slope and run-off channels cut into the landscape ensure that floodwaters and seasonal surge cannot reach the city proper.



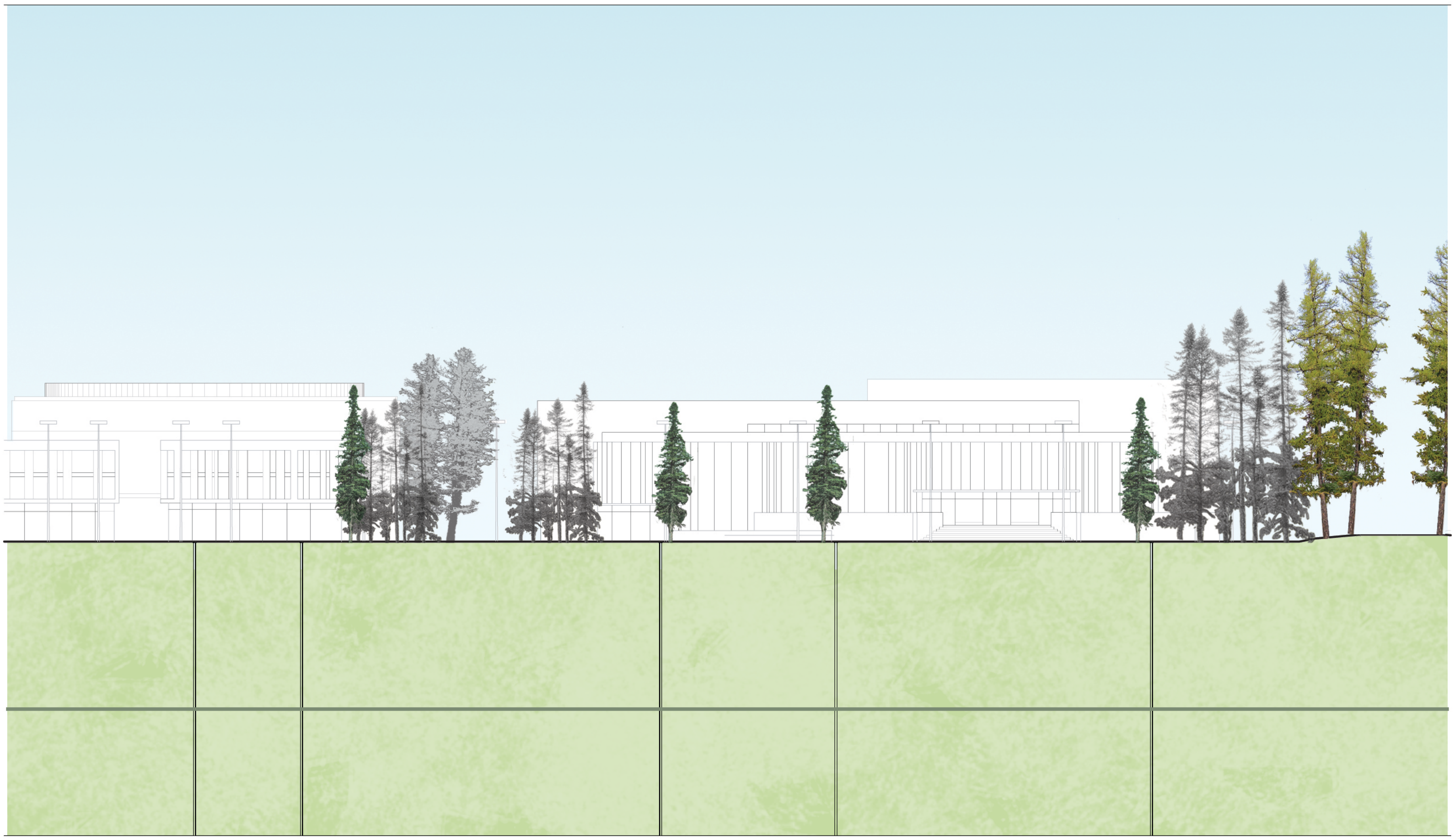
The urban berm is engineered based on techniques typically used in toxic landscape reclamation, and typically used to prevent the leaching of toxic chemicals from polluted sites into the surrounding landscape.

In this case, an urban footing -- composed of layers of clay and stone -- creates a structural backbone for the intervention by creating a container of sorts that will be filled to create the new berm. The new backfill/ berm is separated above and below with a series of geotextiles. these control the flow of material (typically inhibiting that flow) so that any and all pollutants created or deposited within the berm remain within the berm and do not leach into the surrounding the landscape.



A subsurface network has been put in place to collect and recycle a variety of waste water types, including greywater, automobile runoff, urban runoff (from buildings), and storm runoff. On the surface, this wastewater is directed to urban biofilters through a series of channels (see below). Subsurface water is captured using pumps and weeping systems, and is directed to suface collecitons areas to be treated in urban biofilters.

The diagram also shows a subsurface network of geothermal and district heating and cooling shafts (the dotted lines extending below the buildings). In both of these cases, geothermal energy (typically, cold water located deep below the surface) is used to cool bldgs in the summer months. A district heating system is also in place. In this case, subsurface water is collected and turned into steam to be pumped between buildings that share a central heating network. In this way neighbourhoods reduce heating costs and energy expenditures by sharing the costs (environmental and other) of heating buildings.

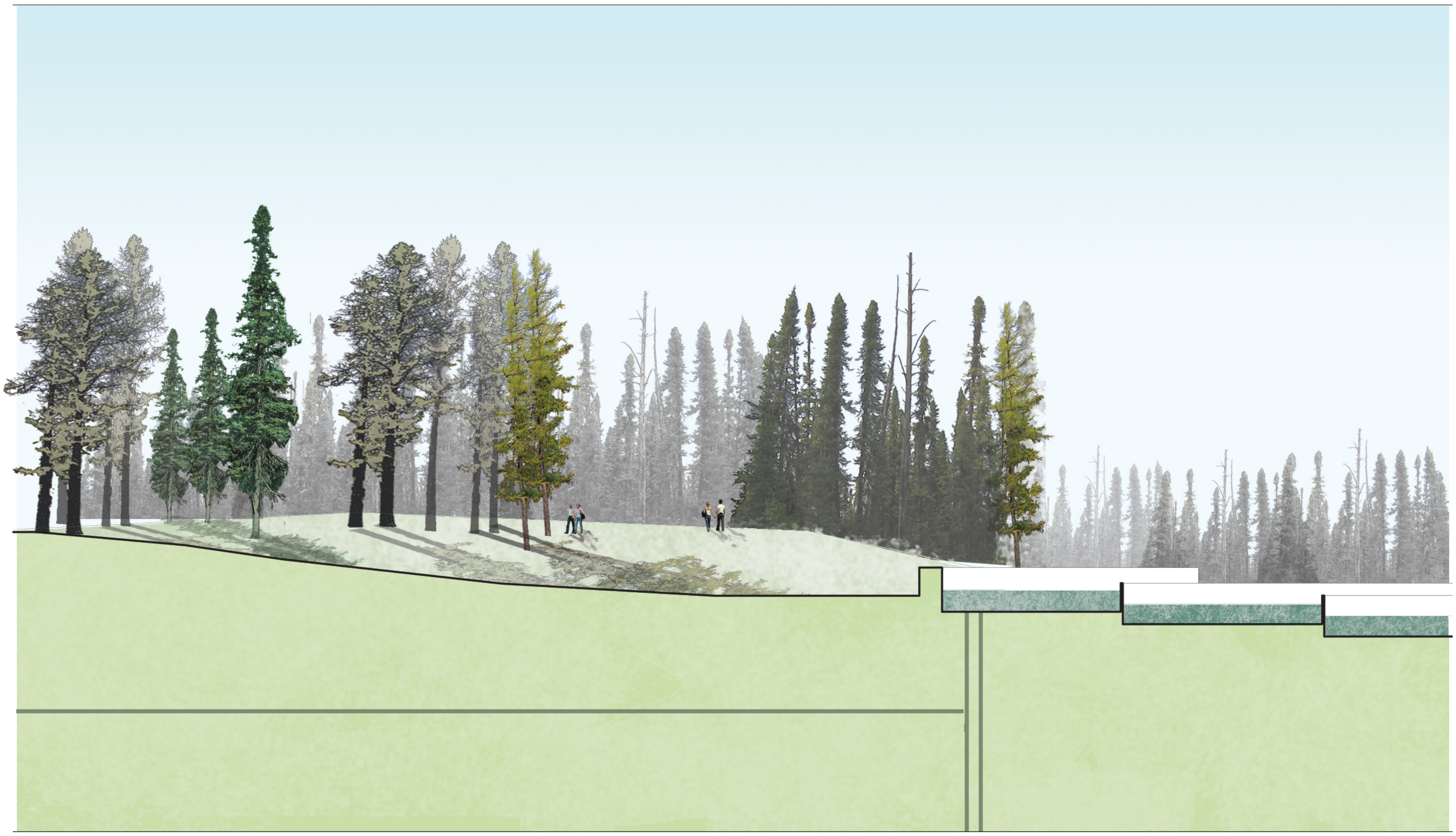


This park occupies a cleft within the urban berm (discussed below). Along with typical park functions, one of several urban biofilter is found here.

The water has been directed here by a series of Urban Channels (shown below).
The urban channels collect and direct run-off from buildings and paved surfaces, and direct it towards the urban marshes. In tandem with the Subsurface Water Network these channels control and direct the majority of runoff produced within the Urban Berm.

Though varying in size and layout, each biofiler typically includes an initial collection pool, a settling pool, and a number of connected ponds/pools/and/or basins through which water passes. Each of these basins is characterized by an increase in the biological complexity of the plants and organisms which are found in it (from bacteria, to small roots and insects, to larger fish, amphibians, and bugs.

The first and second ponds provides pre-treatment, primary and secondary clarification, and chlorine disinfection. Sludge produced during the process is mechanically dried and recycled (as fertilizer).
The majority of the clarification occurs in these two ponds as a result of plant and micro-organism treatment. Plant roots slow the flow of water through the system and provide increased opportunity for the water to interact with bacteria and micro-organisms.



The root systems also filter out suspended solids which are then digested by the micro-organisms found clinging in those root systems. The roots also provide the bacteria with the oxygen they require to assimiliate the organic matter.

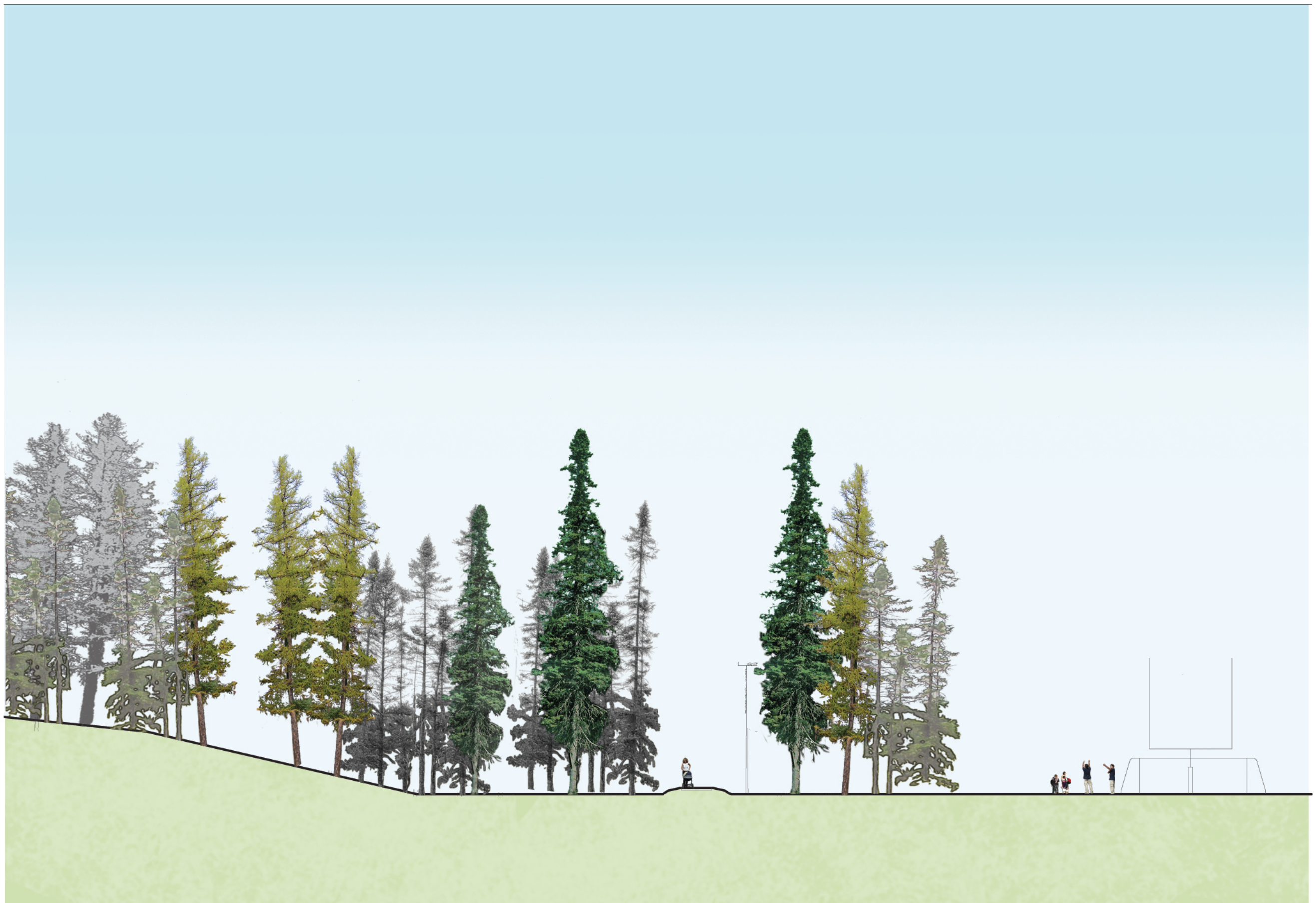
Having been clarified in these ponds, the water then moves into two ponds that mimic a series of local ecological conditions. The first pond has been laced with silt and dead and decaying plant material, and creates a habitat favourable to the river insects occupying the local riparian zone.

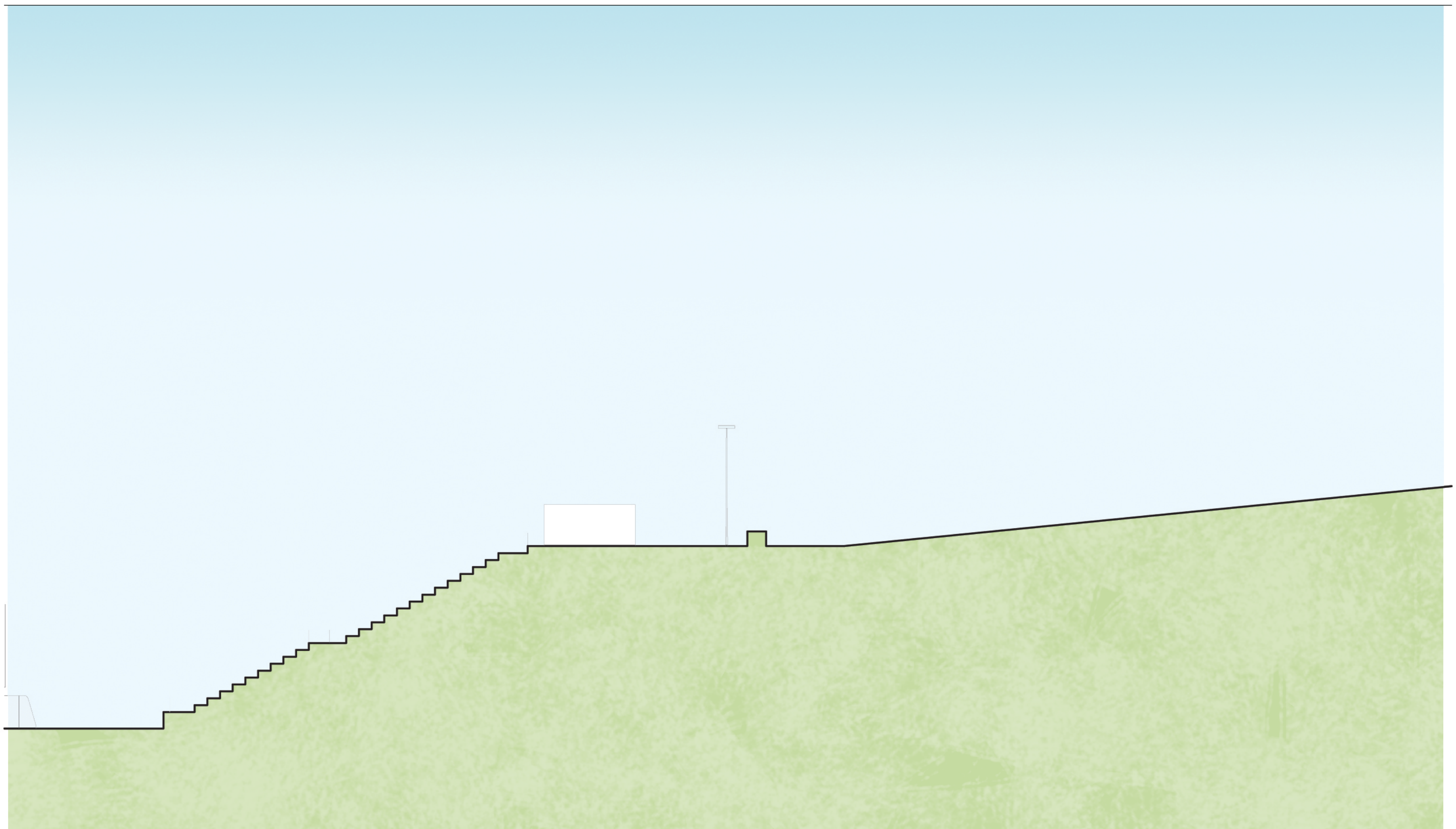
The second pond is planted with local flowering plants and sedges which attract birds and ducks. Continued assisted flow of the water through these two ponds assures a further breakdown of any metals and salts as which may be found in the pretreated water.

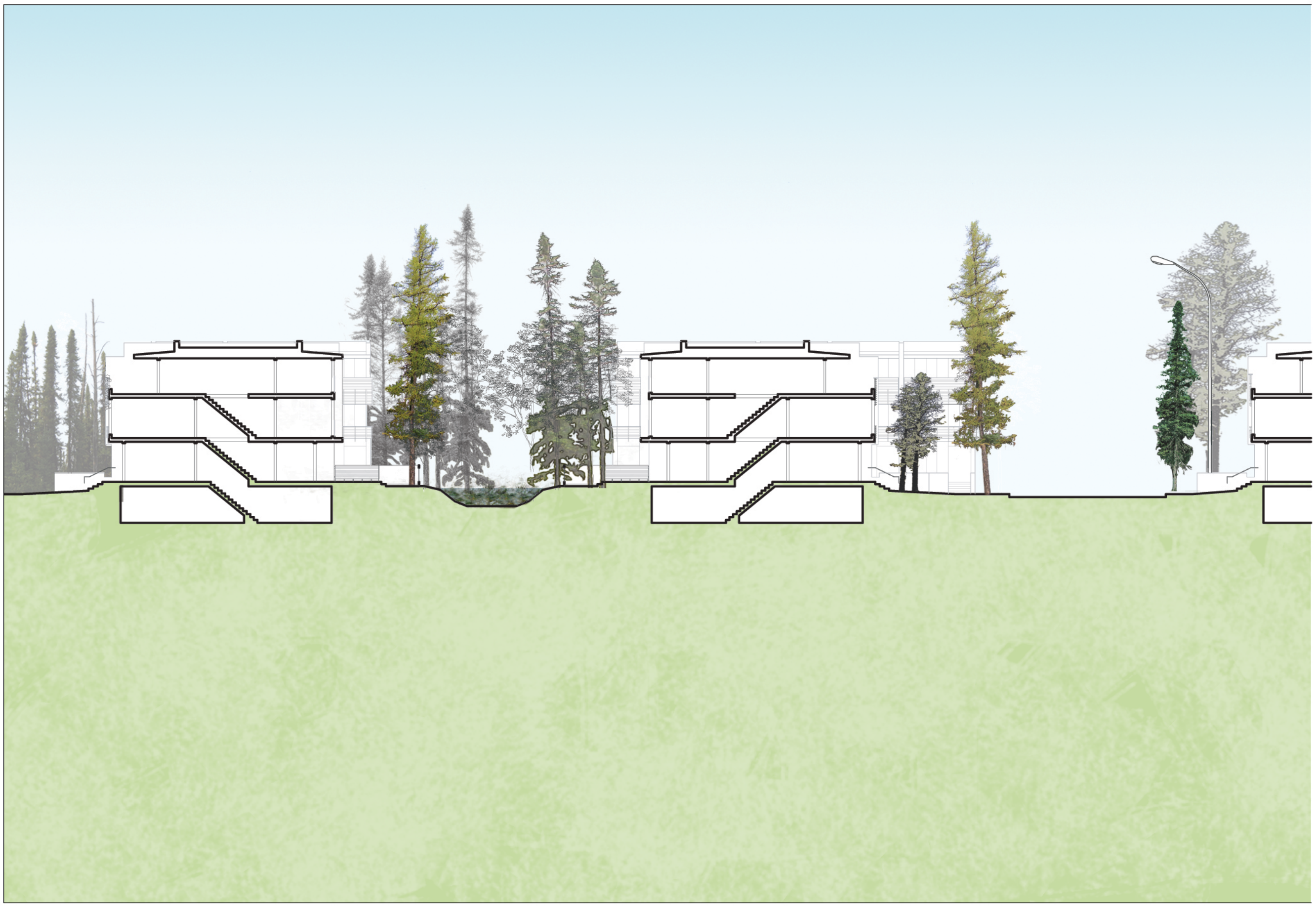
Though the UOF's that are used to process grey-water operate according to the biological principles of a natural wetlands, they are not a replacement for the larger system. Nor are they in and of themselves a necessary component of wetland protection and reconstruction.

Their role is simply to process greywater in an ecologically sensitive manner, and thus, are deployed simply to reduce the ecological footprint of the new urban development.

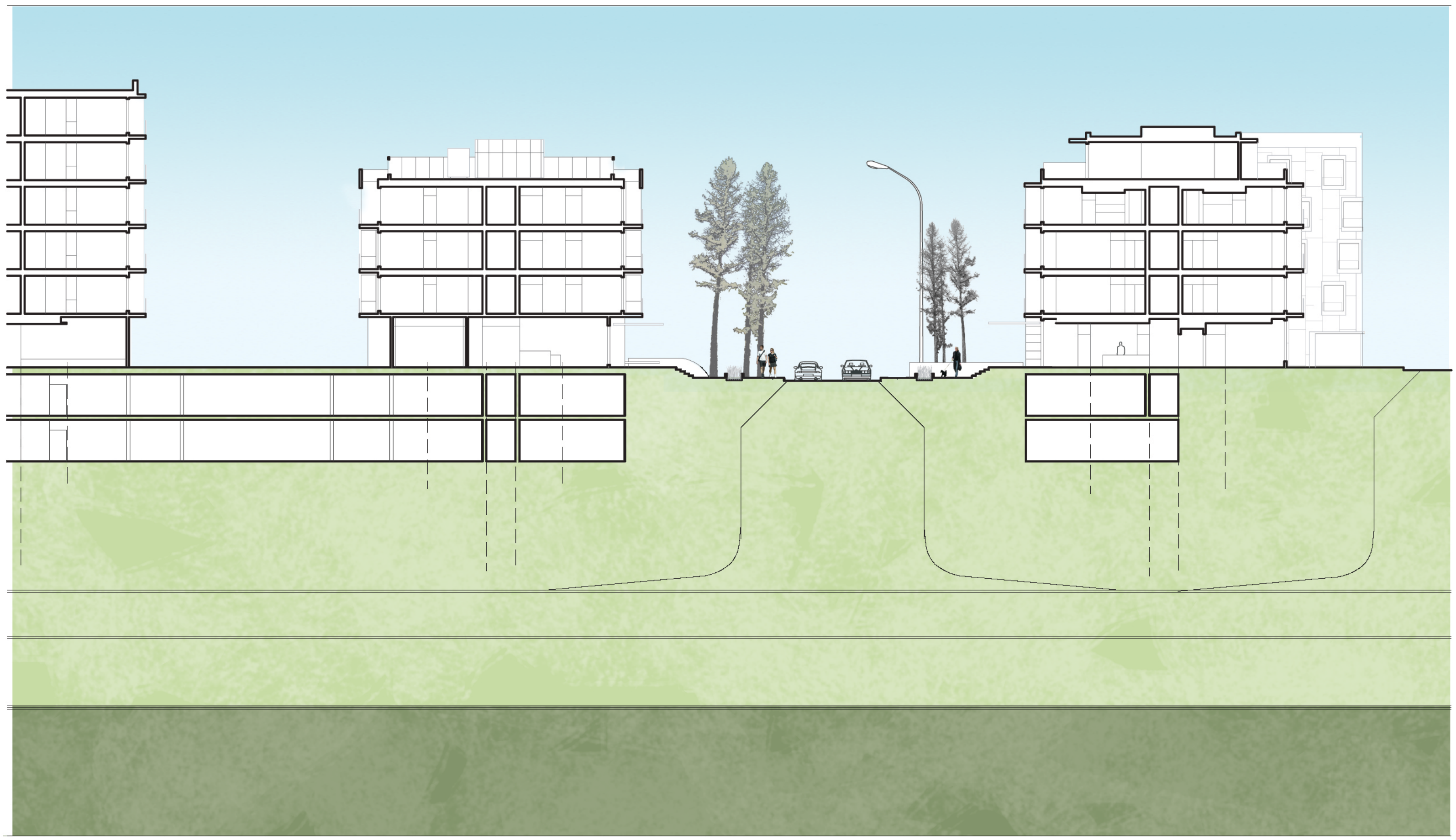
Situated at a low elevation within the town plan, the park doubles as a flood spillway. Though the urban berm protects the town proper from the effects of flooding, the park-spillway provides one location within the plan that allows floodwater the occasional opportunity to flush the landscape beyond the berm. As said above: the strategy proposed by this thesis is landscape centric, and thus, it assumes that flooding will occur. The flood-spillway mitigates against the consequences of that flooding by providing a protected access point for those floodwaters.







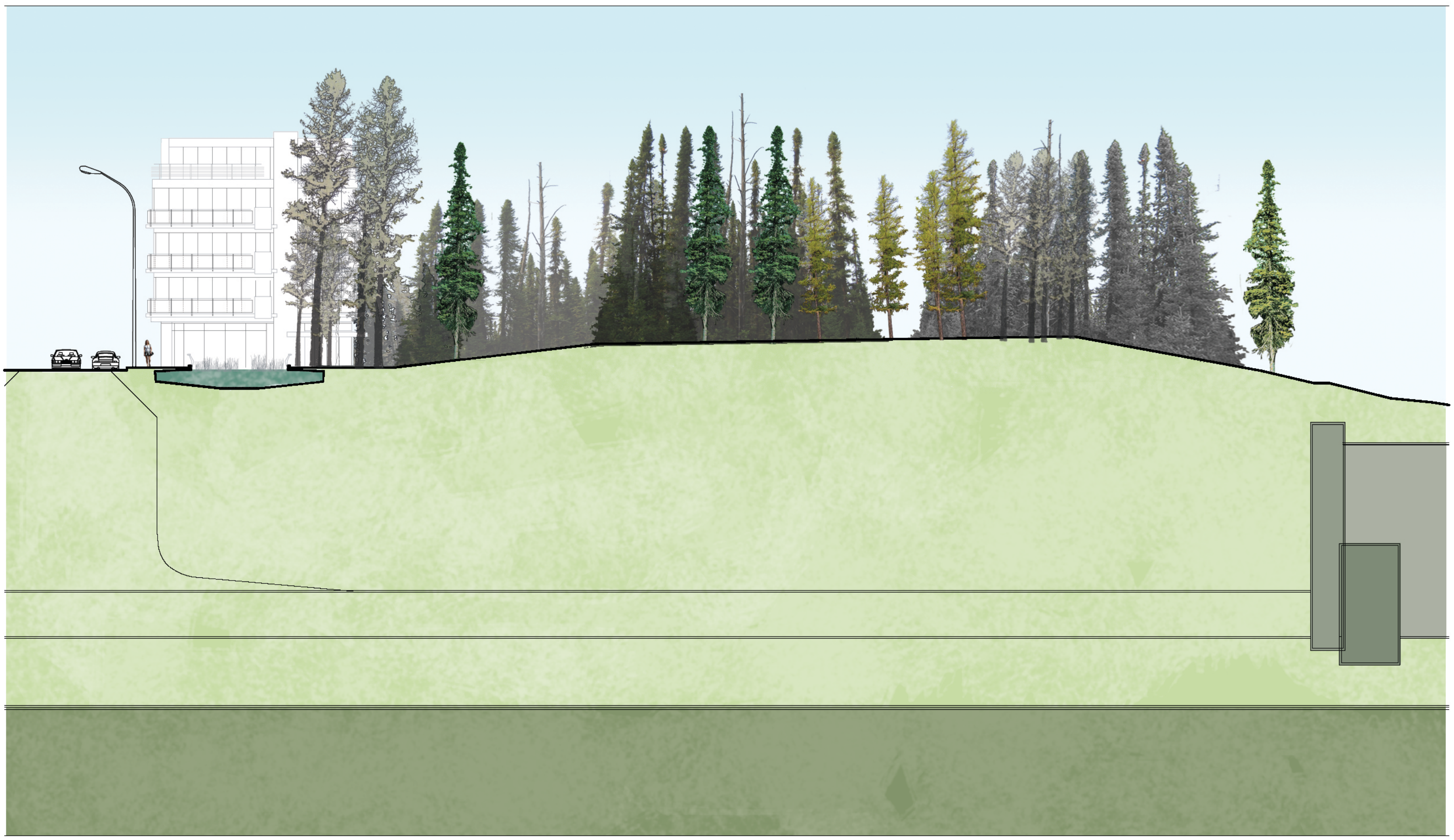
A second community type within the urban plan. In this case, low rise housing, both single family and multi-unit, fronting smaller roadways as well as courtyard conditions. An this scenario, an urban runoff channel runs behind and between the houses, providing a naturalized corridor that will, with time, not only provide amenity to the households that back onto it, but that will create a buffer between the densely arranged housing.



More urban than the smaller and less dense arrangements found within the centre of the urban plan, large scale multi-unit housing creates a ring around the outside of the urban plan. In this scenario, multi-unit housing is interspersed with businesses, amenity, and local services, and in some cases, occupies the same buildings. Note that not only are the blocks arranged in courtyard configurations, but that buildings of different programmatic types are situated within these courtyards, between and behind the smaller buildings fronting the major axes.

This arrangement of large urban blocks containing a variety of programmatic types creates not only densely packed neighbourhoods (reducing overall architectural and urban footprint) but encourages pedestrian circulation between the buildings that provide those different types of programme.

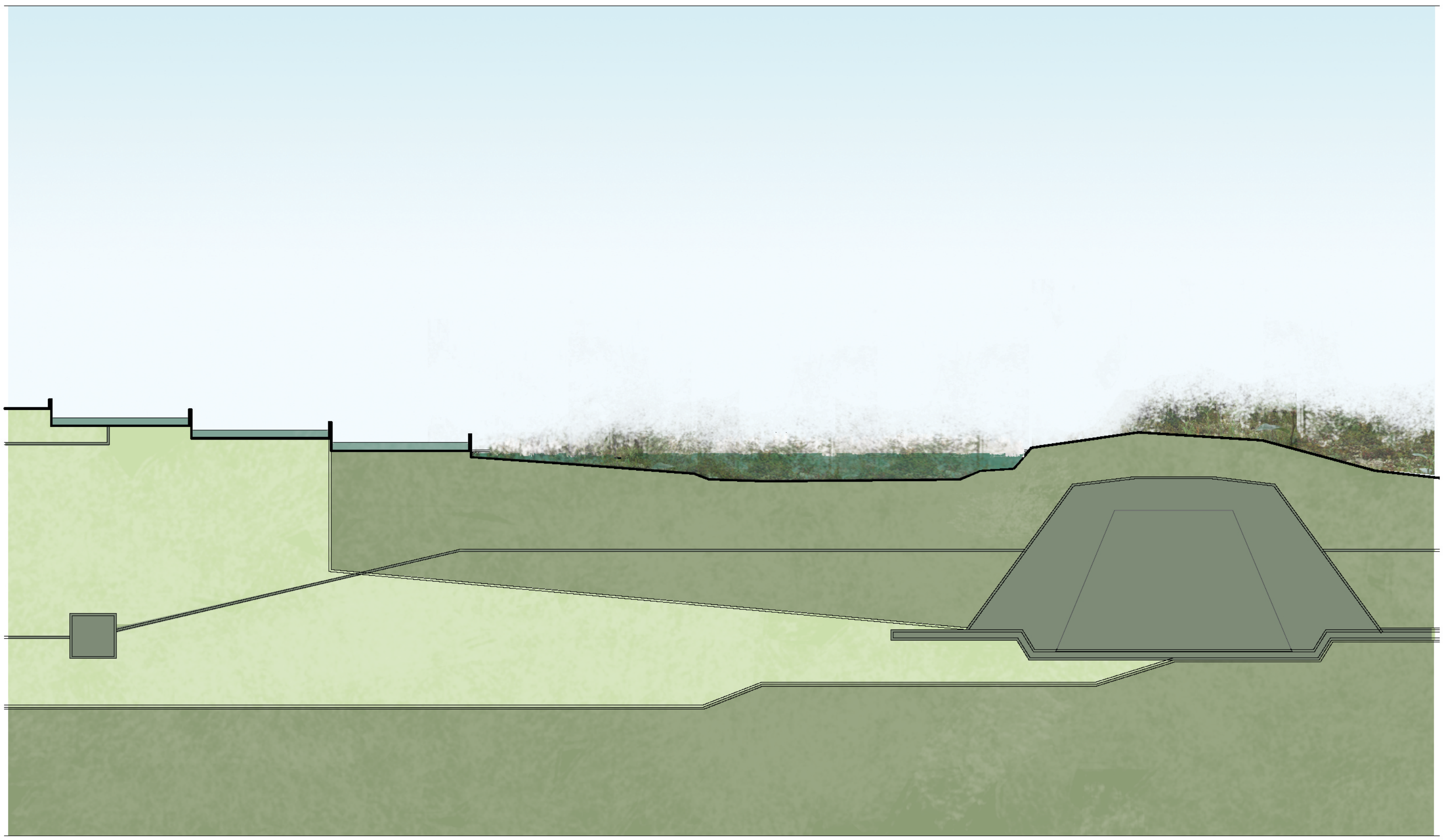
In this section urban runoff is captured by channels that do double duty as naturalized green-strips along the city sidewalks. Runoff from roads and urban blocks is captured almost immediately either within these



channels, or by subsurface systems. These subsurface systems are connected to a variety of water re-use systems. As discussed in Diagram Five, water captured by these systems is either recycled back into a grey water system, used for urban irrigation, or moved directly to an urban filter.

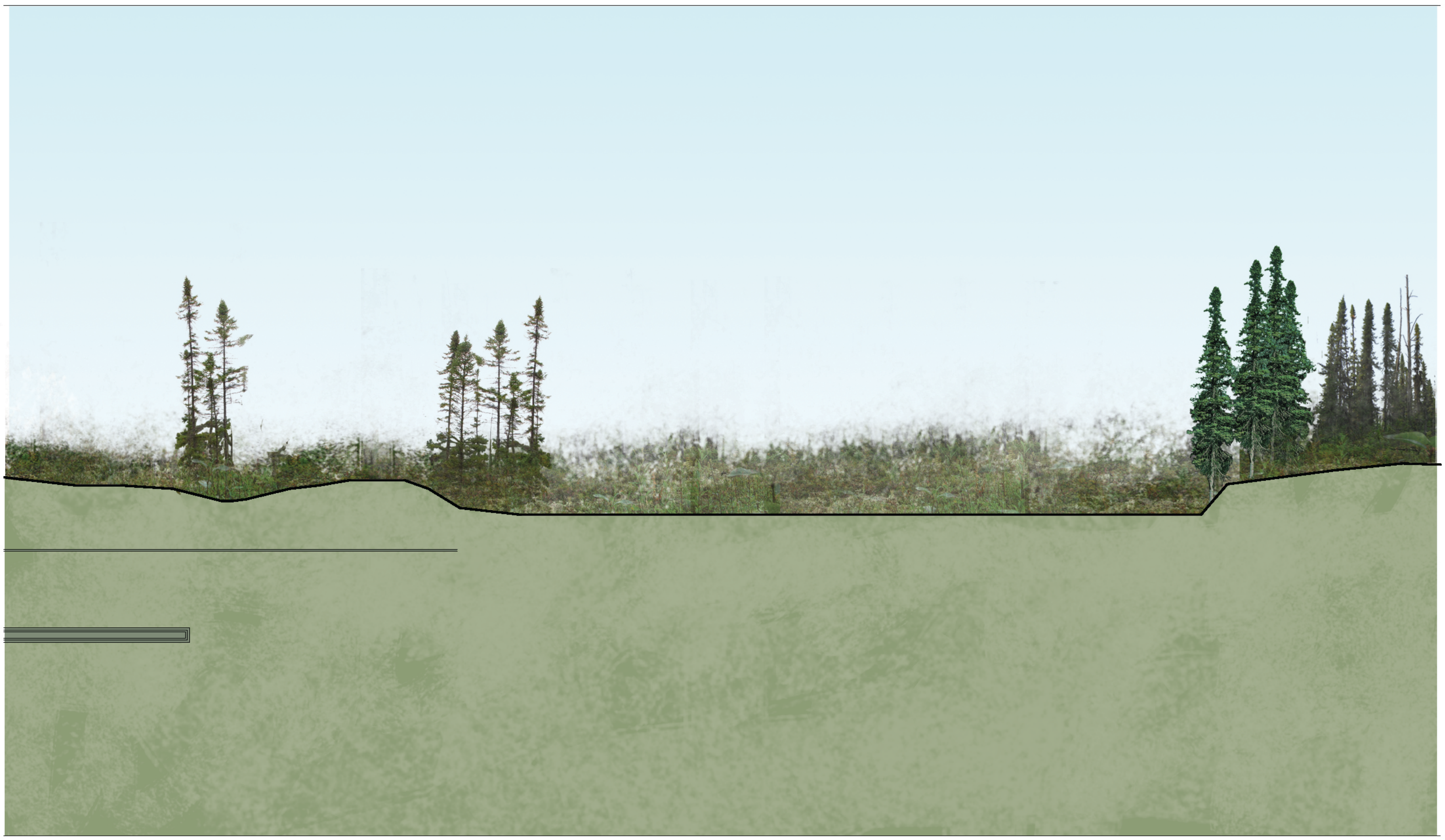
The section also shows the continuous band of geotextiles that separate the urban berm from the surrounding landscape. As discussed above, water that settles within the berm is captured by a systems of weeping tiles, and either recycled in the city's greywater system, or pumped to the urban biofilter. A large biofilter is shown on the facing page, occupying a position adjacent to the berm floodcontrol/runoff retention edge.

The urban berm is bookended by a floodcontrol/runoff retention edge. This slightly elevated lip that circles the city ensures that surface pollutants remain trapped within the urban plan proper.



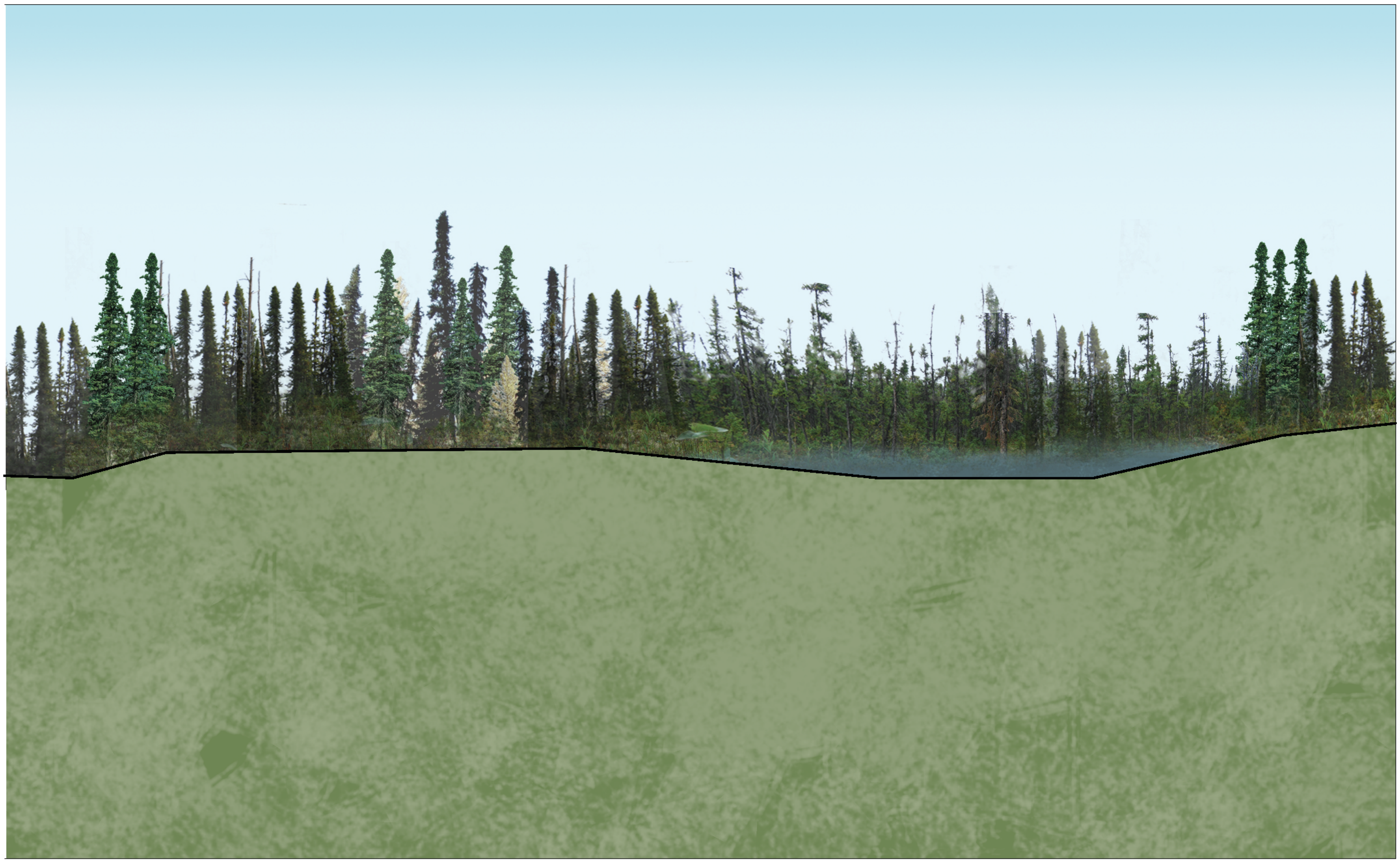
Here we see the transition point between the urban edge (constructed), the hybrid marsh edge (a mediated naturalized condition), and the landscape edge. It depicts the mechanisms by which the urban island is separated from the landscape, as well as showing the manner in which the hybrid zone connects to the large landscape and creates an augmented hybrid condition (by facilitating annual flooding patterns and returning waste bio-matter back to the landscape).

In this case, a terraced biofilter flanks the urban retention ridge. Greywater from the numerous water systems within the town plan (the runoff systems, the greywater systems, the channel systems) is naturally processed and cleaned before being either recycled into the city's urban greywater systems, mechanically treated and recycled in the potable water system, or being pumped to a hybrid marsh buffer at the edge of the berm.



The hybrid marsh extends beyond the edge of the urban berm and the protective seal provided by the layer of geotextiles. In effect, this marsh straddles the buffer zone and acts as one last device separating the urban system from the landscape.

The hybrid marshes fulfill two primary tasks: they protect the surrounding ecosystem (by collecting and purifying urban run-off; by lessening the effects of stormwater surge reabsorption into the local water table, and; by filtering the stormwater of urban impurities before returning it to the local ecosytem), and they create a soft transition zone between urban development and the local ecosystem, allowing local plant and wildlife habitat to renaturalize the urban development's fringe area in a process that mimics natural succession.



Both of these functions lessen the impact the urban development has on surrounding territory, to be sure. More importantly, however, with time this marsh may grow and create a semi-naturlized edge between the city and the landscape, and provide the surrounding wetland with the means to develop its own natural relationship with the urban edge. Since the hybrid marsh is a living buffer zone, growing and shrinking in size, it actively develops means of naturally integrating the edge of the urban plan with the surrounding landscape. The hybrid marsh communicates with the landscape on natural terms, and thus, provides a natural mechanism by which the landscape can can create its own suture between the urban devlopment and the broader ecosystem

A series of pumps is also seen in this section (p159 and p160). These are part of the mechanical system that captures subsurface water and/or that moves greywater between urban channels and filters. In this case pipes are shown exteninding beyond the edge of the urban footing and the layer of protective geotextiles. Water within this system of pumps has been treated within a series of biofilters and is now being pumped back into the landscape as part of a seasonal flushing schedule.   This flushing augments not only the natural delivery of water into the interior of the site, but provides an additional source of nutrient rich water and sediment to the surrounding marsh. The seasonal flush aids in wetland silt development, maintains wetland water volulme and temperature, and ensures wetland replenishment.

Beyond the edge of the urban berm, and somewhere within (or perhaps beyond) the expanding and contracting buffer zone provided by the hybrid marsh, the local landscape adjusts to new local conditions and continues to function in an unimpeded and uncompromised manner.

Footnotes

[1] On the question of ecological scale, the porousity of boundaries between ecological scales, the interconnectivity of ecological activity and processes across scales, cross-scale ecosystem structure, and the dependency of ecosystem structure on actions and processes occurring across scales, see the work of: Magilligan et al (2004), Pahl-Wostl (1998), Gunderson (2002), Sanderson and Harris (2000), Tittler et. al (2006), Urban (2003), Sorooshian et all (2006), Schindler (1998), Walker, Hopkin, Sibly, and Peakall (2006), Murgatroyd et al (1983), Moser (1996), Hanski (1999), Proceedings of the 17th Canadian Hydrotechnical Conference. Hydrotechnical Engineering (2005), Christer (2006), Moldan (2004), Lier (2002), Locky, Davies, and Warner (2005), Dias (1996), Howe et al (1991), Government of Canada (1973 1-7), Hanski (1999), Allen and Hoekstra (1987), and Wrona (2006).

[2] On the question of urban development and the reverberation of ecologically disruptive consequences across ecological scales, see: May et. al (2000), Lier (2002), Ayres (1998), McMahon (1987), National Academy of Sciences (2001), National Research Council (2001), Corner (1999), Pope (1997), Steffen (2008), Mallon (2007), Faludi (2008), Ewing et. al (2008), Georgantzis et al (2000), Arnold et all (1998), Tarnocai (2006), Zhang (2005), United Nations Climate Conference (2009), and Page (1987).

[3] See: United Nations Environment Programme (2002), Environmental Protection Agency (2005; 2006-2), World Tourism Organization (2004), National Research Council (2001), and United Nations Environment Programme (2008).

[4] See Pahl-Wostl (1998), Gunderson (1998), Lier (2002), and Christer (2006).

[5] Consider as an example the parafluvial pond. Many ecologists believe that these ponds constitute a primary structural feature, and thus, they are often present in projects that attempt to duplicate wetland conditions. However, recent research has shown that the structural element is not simply the pond itself, but the relationship that each of those ponds maintains with water temperature, bank stability, and hydrological pressure. And that those relationships are delicate and can be undermined by a simple fluctuation in one of the other components (say for example if temperature drops in the adjacent river, or if a bank is suddenly washed away as a result of avulsion). As it turns out, most of the structural features that define wetlands are actually structural relationships, and the delicate nature of the complex connections that govern those relationships has proven – to date – difficult to duplicate. (see Karaus, Alder, Tockner 2005; Conly, Crosley, Headley 2006).

[6] See Christer, Nilsson & Dynesius (2006); Conly, Crosley, & Headley (2006); Magilligan, Nislow, & Salant (2004); Davies-Colley (1997, 2000); Allen & Hoekstra (1987), and Patrick (1973).

[7] Lier (2002) , Pahl-Wostl (1998), Schindler (1998).

[8] Christer, Nilsson & Dynesius (2006).

[9] Pahl-Wostl (1998).

[10] Hanski (1999), Moldan (1994), Howe, Davis & Mosca (1991).

[11] Magilligan, Nislow & Salant (2004), Gunderson (2002).

[12] Lier (2002), Hanski (1999), Moldan (1994).

[13] A debate surrounding riverbank reconstruction techniques highlights the limiting tendencies of prescriptive approaches and foregrounds their shortcomings in responding to site necessities. Currently, two approaches are used to reconstruct riverbank edges along reconstructed riverbanks. In the first case, riverbanks are left bare to slowly regenerate over time (and thus recreate original conditions). In the second case, banks are planted with mid-growth trees in order to create a root structure and firmly embed the soil at that location.

In the first case, regeneration often fails as the riverbanks are quickly eroded by the adjacent river. In the second case, erosion is indeed slowed, and the bank's lifespan may be longer than in the first case. But often this second method fails when, during flooding cycles, flood waters uproot the trees and tear not only their root structure from the ground and wash away much of the attached riverbank. In the second case, the bank may last longer than in the first case, but when change occurs, it is sudden and catastrophic. In both cases, the riverbank is eventually recreated according to the logic of the river, and according to hydrological cycles, and patterns of avulsion and deposition. (see Davies-Colley (2000), Hanowski (2000), and Schwimmer & Pizzuto (2000)).

[14] In ecologists' words, non-viable wetlands are those in which "complex manifestations of community structure" across time and scales, and in which "general structural attributes" been separated from "direct interactive contact" with other species across "vertical, horizontal, lateral, and temporal thresholds", and in which "the opportunity to adapt to possibility" have been restricted. See Pahl-Wostl (1998), Ward (1989), and Schindler (1996).

[15] Gunderson (2002).

[16] In a landscape-centric approach, responses are generated according to the logic of the landscape. Take flooding as an example. Typically designers would respond to flooding by raising the riverbank, raising the site, raising buildings on stilts, and/or by berming, diking, damning and/or diverting the flooding river. And whereas each of these solutions seems to solve the problem at hand, none do so without compromising the operation of the greater ecosystem, without running the risk of being eventually overwhelmed by the geographically scaled conditions that create this process in the first place.

In a landscape-centric approach, the logic of the ecosystem governs, and the appropriate response is, simply, to allow the flooding to continue, and to develop a response that negotiates these conditions. Only then can a solution that responds to landscape processes be found.

[17] Recalling our discussion above regarding the debate surrounding riverbank reconstruction

techniques, a landscape-centric approach would be one that does not impose a solution on the site (i.e. avoids the question of planting the riverbank altogether), but one that provides the edge condition enough flexibility to return to an ecologically balanced state. See Magilligan (2004).

[18] "Environmental management should be defined as the management of anthropogenic activities with respect to interaction with environmental systems, rather than as the management of environmental systems to meet human perceptions." Pahl-Wostl (1998).

[19] Schwimmer and Pizzuto's work demonstrates that a delicate balance develops between the hydrological and morphological forces in play at the threshold between the riverbank, the adjacent marsh, and the flow of water. In terms of marsh reconstruction, the conclusion we must draw is that any reconstruction of an edge condition will create new dynamics and ultimately will effect the rate and cycle of marsh development, and marsh size. The work also suggests that tampering with that edge condition will have surprising and probably damaging effects on the adjacent marsh.

We are forced to conclude, then, that: 1. recreation of bank characteristics will create new marsh characteristics; 2. that in order to maintain current marsh characteristics we must maintain an untouched bank and create a broad buffer zone between that bank and subsequent construction; and 3. that since this probably is not possible, or rather, since construction will tamper with this dynamic, we must accept that tampering with the bank edge will ultimately create a new marsh dynamic. Which is to say: inevitably we cannot save the current configuration. The question becomes, then, what can we save, and how can we save it.

[20] For a discussion of this theme and the role that subjective assumptions play in influencing the relative success of sustainable interventions, see Geus (1999).

[21] A conclusion drawn from the available ecological literature describing wetland sites, but especially meandering river system sites. Specific statements to this effect are made by, among others, Kuroiwa (2006), Karaus et al (2005), Schwimmer and Pizzuto (2005), Ott (2004), Tockner et al (2004), Charman (2002), Conly (2002), Gunderson and Pritchard (2002), Gatto (1995), Gray and MacDonald (1989), and Heede (1988). Throughout most of the literature that describes recent attempts to rebuild riparian zones and landscape buffers, restore wetlands and/or river systems, create or modify channel systems whether for irrigation, for farm use, or to control run-off, and in engineering handbooks that describe attempts to build roads or bridges in wetland systems, this theme – that meander systems cannot be rebuilt because re-engineering the basic relationships is impossible – recurs. As Ott says: "More than for most other ecosystems, restoring braided rivers means restoring their underlying hydrogeomorphic dynamics… and this is near impossible".

[22] The separation of the two systems may seem like an ultimately damaging move, since the construction required to carry it out would be extensive. But if what Schwimmer and Pizzuto (and their many colleagues who have reached similar conclusions) have concluded about the

delicacy of structural relationships within wetlands is in fact true, then delicacy – as a means of achieving urban integration within a landscape, and as a means recreating ecosystems – hardly matters. What matters in this regard is that the conditions that generate structural properties remain in place, and that the regeneration of structural properties is not limited by moves that continue to undermine landscape processes long after the design is implemented (as is the case with, say, the example mentioned above regarding the techniques used to regenerate riverbanks). This being the case, neither intervention size nor its relative lack of delicacy in regards to its insertion into the existing system bear an impact on the issue of landscape regeneration. Rather, what is important is that designers attempt to maintain, and/or foster the development of, those structural and functional properties that allow the landscape to exist in the first place. And that the possibility of their development is not choked by design moves that limit that growth.

[23] The study of landscape resilience and adaptability tells us that landscapes are not always destroyed as a result of systemic disruption, and that they maintain an ability to absorb changes ("resilience") and adapt to achieve "alternate stable states" – conditions that differ from initial states, but remain viable nonetheless (Gunderson (200)). The study of resilience tells us that this condition derives from functional reinforcement across scales and from functional overlap within scales, and that it is maintained by reinforcing key structuring processes across scales, and by reconnecting processes to new sources of renewal and ecological input and to multiple sources of ecological capital.

As designers we can take advantage of landscape resilience to develop interventions and conditions that coax the landscape into developing new structural relationships, and that nudge the landscape toward new stable states (Wu & Hobbs (2007)). The goal of this kind of intervention would be to maximize this tendency toward adaptability by fostering broadly scaled connections, and our role as designers shifts from imposing solutions to determining processes. Our role becomes meta-structural: capitalizing on this capacity for regeneration we no longer attempt to impose deterministic interventions on a complex system, but rather, we orchestrate conditions such that they foster the development of new relationships and allow the landscape to reorganize itself along lines that it itself has defined. In these terms, the notion of "hands-off" design becomes one in which we seek to influence change rather than control it, and to provide opportunity rather than limiting possibility.

[24] "In discussing competition between two species… we may ask: what would be the outcome if two… species found themselves depending upon the same resources at the same time in conditions where there were no obvious limits to population growth. In this case the species with the greater intrinsic rate of increase… will be expected to become the more abundant, but both populations will grow until they finally come into competition. At this point they will start to affect each other and … there will be a period of instability

until usually the species with the higher [ability to maximize it's efficiency as a predator] alone survives… If two species do occupy the same niche, the one will in the course of time almost certainly always oust the other" Ewer (1972).

[25] And to a lesser extent, to plan for the growth of the urban development. After all, since this proposal lays down the groundwork for urban growth, the strategy we develop must ensure that the moves that will be implemented allow for that growth to occur without compromising the surrounding ecosystem. Some of these issues are discussed in Appendix 7 "On Sustainable Urban Planning."

[26] Of course, depending upon local conditions and contextual ecological conditions, these conditions will differ at every site. This will be discussed in the Conclusion, below.

[27] We are implying, of course, that the designer's job is not to simply apply an accepted remediation technique, but to locate a principle that allows us to reformulate our relationship to the notion of what a solution constitutes in this case.

[28] Many regeneration projects focus on maintaining structural relationships but suffer from the prescriptive tendencies we have described above. See Urban & Rhoads (2003).

[29] A space reserved for river braiding, and implementing means that ensure riverbank stability.

Conclusions

This thesis develops a series of strategies for protecting wetland ecosystems from the ecological consequences of urban development. It is based on the paired assumptions that ecosystems represent networks of linked processes that operate across local and global scales, and that the ecological integrity of any ecosystem can be maintained only if that system's constituent processes are not damaged, and only if ecological damage is prevented from adversely impacting processes occurring across system scales. Thus, this thesis proposes a series of multi-scaled strategies that are developed at both the scale of the site, and more significantly, at the broader watershed scale.

The strategies developed in this thesis protect local ecosystem integrity as a means of protecting the broader wetland ecosystem. It proposes that a series of landscape interventions could provide an ecosystem with the means to protect itself by generating conditions that allow it to reorient itself in new ecological relationships. It promotes ecosystem maintenance and growth by connecting resource rich ecosystems across broad distances. Instead of attempting to recreate and control a complex set of conditions, this strategy creates a framework that allows the landscape itself to generate new relationships, and thereby grow into new stable relationships according to its own structural logic and conditions that it itself prescribes.

To achieve these ends, the thesis proposal conceptualizes landscape as a network of mutually influencing systems linked across a number of scales, and as a phenomenon constituted by a structural framework that can be coerced into regeneration. In this conceptualization the urban development is not viewed as a static intervention that is imposed onto the site, but one which can be eased into, and integrated with, processes occurring within the landscape. The thesis, suggests, then, that developing an ecologically sensitive site requires a close and careful study of both the local system and the broader one of which it is a part.

To achieve this, a design solution deployed within a wetland site must include a site-specific survey of each of the systems operating in the local context, their structural components, throughput and the mechanisms that drive that system, and must demonstrate an understanding of how the system fits into a greater ecological network. Moreover, the solution must identify both the links that bond the local system to the larger network and the broader processes that that design impacts.

Design development must take into account local site dynamics (physical properties, local processes, and structure), must identify systems that are at risk both locally and globally, and must assess landscape assets and processes at the local and regional scale. Furthermore, the design solution must acknowledge that ecological disruption will span multiple scales and systems, and thus, in order to develop means to offset those effects accordingly, must determine where overlap occurs between these systems. A proposal should also demonstrate that attention has been paid to potential directions for future growth, and that current development plans lay the framework for ensuring that subsequent development cannot compromise the site's long-term ecological integrity.

The intevention proposed above achieves these ends by: seeding of the riparian buffer and sediment deposition plain, developing flood inlets to foster lateral trophic links between the river and the site in order to stimulate wetland flushing, seeding of a new marsh network adjacent to the site and the river by implementing moves to stimulate the growth of specific structural features (for example, parafluvial ponds and drawdowns), and the regeneration of local hyporheic zones.

At the broader scales strategies implemented include: the protection and regeneration of ecologies that act as structure for the growth and maintenance of the larger ecosystems, and that shore up the strength and vitality of those large scale ecologies; the setting aside of territory to allow for the regeneration of ecological connections, and the seeding of ecological zones that act as ecological stepping stones, allowing the landscape to create links across broad swaths of territory.

Ultimately, the moves implemented at the site ensure the sustainable integration of the urban development by containing and offsetting the disruption caused by that development, by protecting physical features at both the site and regional scale, by maintaining the site's ecological integrity and replacing processes that overwhelmed by development, and by augmenting the processes already in place such that a new structural framework for the regeneration of local and territorial systems is ensured.

This thesis is based on an extrapolation of techniques and technologies currently being used to remediate damaged landscapes. And though it is a realistic development of those techniques, and years of research has gone into understanding wetlands, wetland functions, and contemporary ecological research and practice, many questions still remain this set of strategies could be implemented.

As ecological and architectural practice stand today, it would seem that a schism exists between the technologies currently being implemented in architectural offices in order to regenerate landscapes, and the research being conducted in order to effectively develop those very techniques. This thesis represents a step forward from current remediation practices, and though it is soundly based within that context, its operational viability – like most wetland remediation occurring today

– remains questionable as a result of limitations inherent in the type of research that is being carried out today by ecologists, and that would need to be carried out if such a strategy were to be implemented.

The overlap between ecological research and architectural development remains scant. In order to fully pursue design ideas of the kind presented in this thesis, research would need to be conducted into the following areas.

Process modeling: the mathematical modeling of conditions to determine how system process operation and interact, and to determine patterns and trends. Such modelling would allow designers and researches to determine the viability of their moves, to understand the interaction of components, and to tweak conditions to strengthen the overall approach determined by the intervention.

Two types of modelling would be required: analytical modelling to describe pre-intervention conditions, and if possible, predictive modelling that could generate series of potential outcomes for design proposal iterations. Conditions to be modelled could include hydraulic flow model (to determine river/riverbank dynamics); flood modeling (to determine volumes and routes); containment modelling (to determine the relative success of control techniques at the riverbank, along the riparian border, and within the hybrid buffer zone); and contaminant fate models (to determine relative success at separating systems).

Research also needs to be conducted to determine the porosity of ecosystem boundaries, and the extents to which they extend through larger and larger systems. Related to this research would be the study of toxin absorption across ecosystems. In both cases an improved understanding of these dynamics (physical and chemical) would lead to the development of improved naturalized riparian and hyporheic intervention techniques. Some research is being conducted along these lines (Walker, 2006), but very little of it has architectural applications.

Research needs to be conducted in the area of cross-scalar physical growth in order to determine whether or not distinct system separation is possible, and to determine whether or not a buffer system would be a viable solution to separating two porous naturalized boundaries. Furthermore, research needs to be conducted into the mechanisms that drive system growth across boundaries, such that the mechanisms of that growth could be identified and timing and patterns of growth ordered. Such research would lead to the design of vastly improved naturalized buffer systems between conflicted ecosystems and the improved design of berming techniques.

Research should be conducted to determine the viability of habitat growth across remediated landscapes. Such studies would highlight growth timeframes, plant and animal population sizes, and related landscape requirements, and thus promote the development of more effect green corridor design.

At the moment, the design of landscape regeneration interventions is either too restrictive, or too broad. That is to say, at one end of the spectrum too little ecological capital is included within a solution, while at the other end, too many elements are forced into a scheme that requires far less input. And since the level of ecological input directly affects the viability of the growth of the new system, research that highlights both the size of, and the relationships between, ecosystem structural features would improve the design of remediated landscapes.

Finally, a set of standards by which to judge the relative success of such efforts would need to be developed. Though much research is being conducted to develop standards by which to quantify a definition of successful landscape regeneration (see World Tourism Organization (2004), Bowler & Cocklin (2002), and Georgantzis & Tarrazona (2002)) the absence of such standards has meant that the design of remediation techniques has had neither benchmarks by which to gauge its relative usefulness, nor standards at which to aim in order to develop successful techniques.

Though based in, and extrapolating from contemporary practice and techniques, the strategies proposed here are unique in a number of ways. Unlike the approaches being deployed presently, the strategy developed here proposes that the intervention and the landscape be integrated across scales. It recognizes that landscapes operate as systems, that these systems are composed of structural features, that the systems have porous boundaries, that landscape operations and processes are neither defined by nor restricted by site boundaries as imposed by development, and that development creates disruptions that ripple across those across scales to impact much larger systems. As such it proposes that any sustainable solution must design beyond the limits of the site.

Unlike contemporary remediation projects, the strategies developed here do not ignore the fact that as designers we cannot control the flow of ecological disruption as it moves from one system to another, nor can we limit the magnitude of its impact across scales. Moreover, it recognizes that the very interventions that are designed to mitigate ecological impact do, in fact, create their own kinds of ecological disturbance. As such it proposes a response that is contained as a discrete system within the larger context, and reinforces this separation wherever possible.

Since it recognizes that landscape conditions are not static, and that they result from predetermining ecological factors which will be irrelevant once development occurs, it does not propose a prescriptive design solution, nor one which predetermines a final outcome that mimics current conditions. As such, it proposes a response that does not attempt to recreate landscape features, but that manages conditions and stimulates such that the landscape can heal itself.

The 8–goal strategy developed in this thesis provides the means to sustainably urbanize a wetland site. Specifically, it outlines a means for developing wetlands in such a way that the surrounding ecological system is protected from the consequences that cascade through it as a result of that development. Most importantly, these strategies provide a means for maintaining the physical integrity of the ecological processes that occur within both the local and the global ecosystems, thereby protecting the operation of ecosystem processes that occur at the broader ecological scales.

This strategies proposed in this thesis aim to protect the physical integrity of developed wetlands, and to maintain the operation of the ecological processes that occur within a site prior to its development. More importantly, these strategies aim to maintain the systemic processes of the greater ecosystem of which the local ecology is a part. To this end we have proposed an approach that attempts to reinstate the structural properties and physical processes of an affected site by creating generative conditions within the landscape, conditions that allow it to evolve into an ecologically stable state after development has occurred[1].

The intervention that is developed in order to address the issues generated by this thesis proposal does not attempt to physically mimic the conditions found on the site prior to construction. Instead of attempting to arrogantly assert our ability to mitigate wetland destruction through the implementation of novel strategies, this proposal accepts that ecological damage is an inevitable outcome of urban development, and that the outcomes of that damage will be recursive through the system and create unknowable consequences. Proceeding from that basis, this thesis develops an approach that is landscape-centric and that privileges the ongoing operation of landscape processes that are outside of our ability to control. And though we have not shunned the need to intensively reshape the landscape conditions found on and near the site, ultimately, the ideas proposed in this thesis represent a soft intervention – territorially scaled to be sure, and not unwilling to make bold gestures within the landscape when necessary – but one that attempts to neutralize the impact of our interventions by embedding them within natural systems in such a way that damage to that system is minimized, and that offset their impact by initiating processes that do not force prescribed solutions upon a system but that allow for a measure of adaptability such that new processes can develop over time that lay the groundwork for creating processes that allow the landscape to heal itself.

And though the results that it generates (in the short term) and the interventions that it implies in this instance might resemble those defined by a more prescriptive approach, the strategies outlined here differ from those approaches in fundamental respects.

The goal-based approach outlined here does not imply the application of a set of predetermining moves that impose a desired result. Rather, it represents a set of guidelines and targets that allow for the management of conditions in order to seed preferred ends; in other words, it generates a system of processes that are capable of nesting within pre-existing dynamics in such a way that the entirety is now able to adapt in response to feedback from external inputs. As such it becomes capable of negotiating new conditions as a condition of its ability to evolve and grow. Unlike a more prescriptive approach, this set of strategies is more than just a collection of techniques whose application generates a series of predetermined top-down causal relationships. Rather, it is an open-ended system; it does not define a solution but allows for the generation of processes that nurture landscape regeneration on its own terms. It allows for adaptation in response to feedback from external inputs, and as a result, allows the intervention that develops over time to negotiate new and unforeseen conditions as it evolves in tandem with the broader system of which it is a part.

Ultimately, this approach represents more than just the setting aside of a managed eco-system within specified territorial limits (limits that will, with time, generate an ecologically disconnected – and thus, ecologically useless – parkland condition). Rather, this approach represents a full integration of ecosystem processes both new and old, achieved by creating overlaps between pre-existing conditions and new processes that evolve according to the logic of the system already in place (and thus, that allow for natural development and change as the systems evolves over time). Stated in other terms, rather than imposing an overarching (i.e. prescriptive) program for maintaining an isolated ecosystem, this approach embeds new generative processes within the greater system in such a way that adaptation to new conditions and growth and change remain possible. It fosters, in other words, the generation of a viable ecosystem, connected to other ecologies, and functioning within a network of connected systems.

This thesis envisions a hybrid form of infrastructuralized landscape in which the blurring of boundaries between architecture, infrastructure, and landscape design become a means by which an ecosystem reorients itself into new ecological relationships in order to ensure its long term viability. It is one which requires little intervention once the initial conditions are put in place since it generates a series of self-sustaining naturalized processes. Ultimately it creates a hybrid infrastructure that mediates between landscape and urban development – a kind of instrumental landscape of active and activating landscape interventions operating across scales to create generative processes that allow an ecosystem to heal itself.

Footnotes

[1] To recap: we examine the links that exist between local structural phenomena and the operation of the watershed system as a whole, and, by coming to a specific understanding of the hydrological, structural, and morphological properties that allow the wetland to exist and to propagate, we develop methods for reinstating landscape processes once they have been disturbed. A new system is inserted into the existing condition as a separate and distinct phenomenon. Links between it and existing conditions are radically severed. A series of moves is then implemented locally to protect the physical features of the adjacent site and the processes operating there, to contain and offset the damage created by development, to maintain the site's original ecological

integrity to as great an extent as possible, to replace processes that may have been disrupted or overwhelmed by development, to augment the processes already in place in order to create a structural framework for new processes which will be instituted at the broader regional level, and to foster conditions that allow the landscape to generate broadly-scaled connections and reconnections to systems and landscapes operating territorially.

appendix

Comprehensive List of Species

The Boreal Forest is an ecologically rich ecozone, characterized by a diversity of plant and animal life, some found nowhere else.

What follows is a comprehensive list of plant and wildlife found with the Broeal Forest.

WILDLIFE
- bat, big brown Eptesicus fuscus
- bat, little brown Myotis lucifugus
- bears, black Ursus americanus
- beaver Castor canadensis
- bison, wood Bison bison athabascae
- bison, plains Bison bison bison
- caribou, woodland Rangifer tarandus caribou
- caribou, barren ground Rangifer tarandus groenlandicus
- coyote
- fox, arctic Alopex lagopus
- hare, snowshoe Lepus americanus
- lynx Lynx canadensis
- mink Mustela vison
- moose Alces alces
- muskrat Ondatra zibethica
- muskox Ovibos moschatus
- wolf, gray Canis lupus
- wolverine Gulo gulo

Transitory wildlife includes:
- deer, white-tailed Odocoileus virginianus
- fox, red Vulpes vulpes
- porcupine Erithizon dorsatum

BIRDS
RAMSAR has designated 4 sites in Alberta as "rare". Up to 400,000 birds arrive here during spring migration, and more than one million occur in the fall.

The Boreal Forest contains 227 bird species including:
- chickadee, boreal Parus hudsonicus
- crane, sandhill Grus canadensis
- crane, whooping Grus americana
- crossbill Lorix
- diver Gavia
- eagle, bald Haliaeetus leucocephalus
- falcon, peregrine Falco peregrinus
- goose, Canada Branta canadensis
- goose, snow Anser caerulescens
- goose, white-fronted Anser albifrons
- godwit, hudsonian Limosa haemastica
- grebe, North American Podicipedidae (all (7) north american species)
- grouse, spruce Dendragapus canadensis (formerly Falcipennis canadensis)
- hawk, red-tailed Buteo jamaicensis
- longspur, smith's Calcarius pictus
- nuthatch, red-breated Sitta canadensis
- owl, great grey Strix nebulosa
- owl, pygmy Glaucidium califomicum
- owl, snowy Nyctea scandiaca
- pintails Anas acuta
- ptarmigan, willow Lagopus lagopus
- redpoll Acanthis
- swan, tundra Cygnus columbianus
- swan, whistling Cygnus columbianus
- thrush, hermit Catharus guttatus
- vireo philadelphia Vireo philadelphicus
- warbler, blackpoll Dendroica striata
- warbler, bay-breasted Dendroica castanea
- warbler, cape may Dendroica tigrina
- 25 duck species

REPTILES AND AMPHIBIANS
- frog, leopard Rana pipiens
- frog, chorus Pseudacris triseriata
- frog, wood Rana sylvatica
- snake, eastern ribbon Thamnophis sauritus
- snake, plains garter snake Thamnophis radix haydeni
- snake, red-sided garter Thamnophis sirtalis parietalis
- toad, Canadian Bufo hemiophrys
- toad, western Bufo boreas

FISH
-36 recorded species including:
- burbot Lota lota
- cisco Coregonus artedi
- darter, Iowa Etheostoma exile
- grayling, arctic Thymallus articusi
- inconnu Stenodis leucicthys
- minnow, brassy Hybognathus hankinsoni
- minnow, emerald shiner Notropis atherinoides
- minnow, fathead Pimephales promelas
- minnow, finescale dace Phoxinus neogaeus
- minnow, flathead chub Platygobio gracilis
- minnow, lake chub Couesius plumbeus
- minnow, longnose dace Rhinichthys cataractae
- minnow, northern redbelly dace Phoxinus eos
- minnow, pearl dace Clinostomus elongatus
- minnow, redbelly dace Phoxinus eos
- minnow, spottail shiner Notropis hudsonius
- mooneye Hiodon alosoides
- perch, yellow   Perca flavescens
- pike, northern (alt. pickerel, jackfish) Esox lucius linnaeus
- quillback Carpiodes cyprinus
- redhorse, shorthead Moxostoma macrolepidotum
- redhouse, silver Moxostoma anisurum
- sauger Sander canadensis
- shiner, emerald Notropis atherinoides
- shiner, spottail Notropis hudsonius
- shiner, river Notropis blennius
- sturgeon, lake Acipenser fluvescens
- sucker, longnose (var. white sucker) Catostomus catostomus
- sucker, mountain Catostomus platyrhynchus
- sucker, white Catostomus commersoni

- trout, brown Salmo trutta
- trout, bull Salvelinus confluentus
- trout, lake cristivomer namaycush
- trout, rainbow Oncorhynchus mykiss
- whitefish, lake Coregonus clupeaformis
- whitefish, mountain Prosopium williamsoni

Spawning fish include:
- goldeye Hiodon alosoides
- sticklebacks Gasterosteus aculeatus
- walleye Stizostedion vitreum

VEGETATION
- alder Alnus
- aspen, trembling Populus tremuloides (upland)
- bog birch Betula pumila
- pine, jack Pinus banksiana
- pine, lodgepole Pinus contorta (var. latifolia),
- not on our site, but along the slopes on western edge of Wood Buffalo Park.
- poplar, balsam Populus balsamifera (near water)
- spruce, white Picea glauca
- spruce, black Picea amariana,
- tamarack (larch) Larix laricana
- willow Salix
- muskeg
- sphagnum moss Sphagnum cymbilifolium

Grasses and heath plants include:
- bog birch (plant) Betula glandulosa
- bog laurel Kalmia polifolia
- bullrushes
- common cattail Typha latifolia
- Narrow Leaf Cattail Typha angustifolia
- bulrush Typha capensis
- northeastern bulrush scirpus bicolor
- green bulrush scirpus atrovirens
- cloudberry Rubus chamaemorus
- fern, mingan grape Botricyium minanense
- fern, leathery grape Botricyium multifidum
- fern, siberian polypody Polypodicum sibiricum
- narrowleaf goosefoot, Chenopodium leptophyllum
- grass, annual wheat Eremopyrum triticeum
- grass, bluejoint reed, var bluestem   Calamagrostis canadensis
- grass, buffalo   Buchloe dactyloides
- grass, tufted hair Deschampsia caespitosa
- grass, needle   Stipa nelsonii
- grass, northern manna Glyceria borealis
- grass, northern rough   Festuca scabrella
- grass, polar Arctagrostis arundinacea
- grass, skunk Eragrostis megastachya
- juniper, creeping Juniperus horizontalis
- moss, peat Sphagnum angustifolium
- moss, twisted bog Sphagnum subsecundum
- parsnip, water Sium suave
- pitcher-plant Sarracenia purpurea
- quillwort Isoetes Echnisopora
- reed, narrow leaved burSparganium angustifolium
- rosemary, bog Andromeda polifolia
- sagebrush Artemisia tridentata
- sagebrush, wormwood Artemisia tilesii
- sedge, awned Carex atheroides
- sedge, few fruited sedge Carex oligosperma
- sedge, hay Carex siccata
- sedge, marsh beaked Carex rostrata
- sedge, miscellaneous carex arcta, c. backii, c. capitata, c. heleonastes, c. heteroneura, c. hookerana, c. houghtoniana, c. hystericina, c. lacustris, c. loliacea, c. oligosperma, c. pauciflora, c. pedunculata, c. pseudocyprus, c. tonsa. c trisperma, c. umbellata, c. vulpinoidea
- sedge, water Carex aquatilis.
- sundew Drosera rotundifolia
- threeleaf goldthread   Coptis trifolia

INSECTS & INVERTEBRATES
- beetles (incl boreal water beetle Dysticus alaskanus) (4 species)
- black flies Hexatoma simulidae (12 species)
- caddisflies Trichoptera (275 species)
- dragonflies (72 species)
- mayflies Ephemeroptera (122 species)
- midges Nematoceran diptera (100s of species)
- mosquitos Culicidae (43 species)
- stoneflies Plecoptera (200 species)

ENDANGERED SPECIES
There are 12 endangered species in the Boreal Ecozone, including:
- wolverine
- woodland caribou
- wood bison
- leopard frog
- canadian toad
- arctic grayling
- bull trout
- lake sturgeon
- pygmy owl
- peregrine falcon
- whooping crane
- the bay-breasted warbler

fig a.1, From left to right (top): twisted bog moss; willow ptarmigans on a creekbank in northern Alberta; a pack of lynx on a road north of Fort McKay; a sundew plant; poplar fluff caught in tufted hair grass; great horned owls. (bottom): a whooping crane on the shores of the Athabasca; the northern pygmy owl; a nuthatch, an awned sedge plant; a beaver dam; a sandhill crane; bison.







Glossary

Aggradation: the process by which a stream's gradient steepens due to increased deposition of sediment; the accumulation of sediment in a stream channel on an alluvial fan or on a floodplain; to raise the channel of a river by depositing sediment and similar materials.

Anastomose: the coming together of branches of a river into a single stream (anastomoses, anastomosising).

Avulsion: a sudden cutting off of land by flood, currents, or change in course of a body of water; a forcible separation or detachment.

Bank Migration: the process in which a river's banks reposition themselves laterally in response to changes in alluvial pressure, hydrogeomorphic fluctuations, seasonal cycles, and/or erosion and deposition; the process in which individual soil particles of a stream bank are carried away as the stream channel moves.

Bankfull: a flood tide that rises to the level of banktop; the point at which the flood tide begins to spill over onto the channel side zone (see also over-bank tide).

Bankfull Stage: stage during which channel reformation (or maintenance) – that is the removing of bars, and the forming or changing of bends and meanders – as a result of moving sediment discharge is most effective and results in typical channel shape, size and characteristics.

Bar: a low ridge or wedge shaped deposit of sediment accreting along the inside bank of a meandering stream where water velocity is low; a linear (long and narrow) shoaling landform developing where water current promotes deposition of granular material within a body of water. Sediment grain size is directly related to river current strength (see also braid bar, laterally accumulating floodplain sediments, and transgression lineaments).

Benthic: living in or on the bottom of a body of water.

Braid Bar: the temporary islands separating the network of small channels that appear adjacent to meandering rivers (see also bar).

Bummock: the submerged counterpart of a hummock (see also hummock).

Denudation: stripping of a river bank (see also devegetation).

Devegetation: the removal of vegetation and exposure of bare soil throughout at least one growing season.

Deposition: the geological process whereby material is added to a landform (also sedimentation).

Drainage Basin: the extent of geographical area in which all surface drainage flows to a single outlet stream; the geographical area drained by a single outlet stream.

Drainage Density: the relative density of natural drainage channels in a given area usually expressed in terms of kilometres of natural drainage or stream channel per square kilometre of area. Obtained by dividing the length of the stream channel by its drainage area.

Drainage Patterns: drainage path that runoff follows within a given area.

Drawdown Curve: plot of the decline of water table (piezometric level) versus distance from a pumping source, or versus time at a given distance from a source. Rates of flooding at a channel or river edge and rates of tidal flushing of bank sediments are directly proportional to steepness of the curve; i.e. wetland flushing as a result of tide action and flooding is directly proportional to high steepness of the drawdown curve.

Dynamic Equilibrium: the state wherein system output changes continually but remains within fairly narrow bounds; the condition of balance between varying, shifting, and opposing forces.

Ecocline: a landscape boundary between two ecosystems which is not sharply defined but in which the distinction between the two is characterized by gradual and continuous change in both environmental conditions and community composition; the joint expression of associated community and complex environmental gradients.

Ecotone: a transition area between two adjacent ecological communities. Can arise naturally (such as a lakeshore) or by human intervention (such as an agricultural field cleared from a forest). Ecotonal communities retain characteristics of each bordering community and often contain species not found in adjacent communities. Examples include: fencerows; forest to marshland or forest to grassland transitions; riparian zones and land-water interfaces. Characterized by vegetational sharpness, physiognomic change, occurrence of a spatial community mosaic, presence of exotic species, and species richness higher or lower than on either side of the ecotone.

Ecotope: an ecologically distinct unit within a landscape; a landscape area of ecologically distinct and uniform conditions and characteristics.

(Fluvial) Entrainment: the capture and transport of bank material for deposition elsewhere; the mobilization by flowing water of sediment or organic debris from the bed or banks of a stream channel. Also referred to as "sediment load transport".

Eutrophic Water: water with a supply of nutrients capable of supporting rich organic productions (see also trophic level).

Eutrophication: a process of enrichment of river and lake water; the effect of nutrient addition on aquatic communities. Can be positive, negative or negligible depending upon nutrient status of the river and degree of nutrient dilution.

Flow Regulation: the control of natural water flow by means of water diversions, impoundments or withdrawals.

Flyway: a geographic migration pathway for birds, including breeding and wintering areas.

Food Chain: the hierarchical feeding relationships that exist between species with an ecosystem; the complex intermeshing of individual food chains in an ecosystem.

Full Water Cycle: term used to describe the water cycle as an entirety that encompasses a series of processes linked across both the watershed and the continental scale.

Fluvial: of, pertaining to, inhabiting, or produced by the action of a river or stream.

Grachtenstad: a reclaimed marsh (see also geestgrond and terpen).

Geestgrond: a town built on hardened peat (for example, Haarlem and Alkmaar within the Netherlands) in a reclaimed marsh (see also grachtenstad and terpen).

Hummock: a small, rounded or cone-shaped rise of fertile, densely wooded land that is higher than a surrounding marsh; a low mound, usually of peat, caused by frost heaving; a microtopographic elevated area on a raised bog, composed principally of hummock-forming species (see also bummock).

Hypogeic: living beneath the soil.

Hyporheic Zone: the area under or next to a streambed in which water in a stream channel has moved into subsurface streambed. A spatially fluctuating ecotone between the surface stream and the deep groundwater where important ecological processes and their requirements and products are influenced at a number of scales by water movement, permeability, substrate particle size, resident biota, and the physiochemical features of the overlying stream and adjacent aquifers.

Impoundment: in hydrological engineering refers to the damming or channeling of a body of water by artificial means, or the creation of a hard edge along the bank of a body of water; the body of water confined by a dam, dike, floodgate, or other barrier; the reservoir where water is held behind a control structure.

Karst topography: Karst topography is a landscape shaped by the dissolution of a layer or layers of soluble bedrock, usually carbonate rock such as limestone. Caused by subsurface drainage, or the presence of either active or inactive subsurface water channels. Karst topographies are characterized by the presence of sinkholes.

Lability: in hydrological sciences does not refer to susceptibility to change or instability but the capacity for a landscape or body of water to adjust to changes downstream from a source of change.

Laterally Accumulating Floodplain Sediment: sediment deposited as a result of recurrent avulsion and deposition at a river's edge; the long striated mounds observed parallel to meandering river banks. LAFS are not permanent features but move and transform as a result of sediment flow and hydrological pressure (see also bars and transgression lineaments).

Lentic: of or related to still or standing water (see also lotic).

Littoral: the region of the banks of a river, lake or estuary; of or relating to a coastal or shore region; the zone between high tide and low tide; pertaining to or along the shore, particularly to describe currents, deposits and drift.

Lixiviation: the extraction of solubles and polluting substances by water flowing under the effect of gravity.

Lotic: of or relating to moving water systems (see also lentic).

Mainstem: the primary path of a river.

Mesocosm: a system larger than a microcosm but smaller than a macrocosm; physical enclosure or state designed to approximate natural conditions, and in which environmental factors can be manipulated.

Metapopulation: a set of local populations within some larger area where typically migration from one local population to at least some other patches is possible; a population constituting one unit that parses itself into patches where adaptation is easiest; the population of populations of a specific organism; a group of geographically separated organisms of the same species, unevenly distributed across a spatially heterogeneous, but naturally or artificially fragmented, landscape; several distinct populations of the same species together with the landscape they inhabit.

Moving Littoral: the movement of the shoreline as the boundary between water and land moves across the river-floodplain system during expansion and contraction cycles.

Over-Bank Tide: a tide that rises above the bankfull stage is termed an over-bank tide (see also bankfull).

Parafluvial Ponds: short-lived, discrete, aquatic "islands" within the floodplain matrix, they are expected to contribute disproportionately to aquatic biodiversity. Very sensitive landscape elements, they disappear as a consequence of river regulation, the removal of vegetation, changes in temperature, humidity, or air pressure, changes in fluvial pressure, and flow control.

Progradation: the outward advance of a shoreline resulting from the nearshore deposition of sediments by a river.

Reaeration: the recharging of dissolved gases in water.

Refugia: areas from which recolonization begins after a disturbance event occurs. Their distribution and utilization is of critical importance for maintaining the ecological stability of systems.

Riffle: a shallow area of a stream in which water flows rapidly over a rocky or gravelly streambed.

Riparian: relating to or living or located on the bank of a natural watercourse; the zone of transition from an aquatic to a terrestrial system, dependent upon surface or subsurface water.

Riparian Zone: the linear interface forming a transition area between an aquatic system and the adjacent land. Healthy riparian buffer zones are widely recognized for their ability to to maintain or improve water quality along a riverbank edge; stabilize stream channels; provide erosion control by regulating sediment storage, transport, and distribution; provide organic matter that is critical for aquatic organisms; serve as nutrient sinks for the surrounding watershed; provide water temperature control and serve as key recharge points for renewing groundwater supplies.

Shifting Habitat Mosaic: the ongoing reconfiguration and reconstitution of an ecosystem (biotic distributions and biogeochemical cycles) as a result of the recurring cycle of alluvial processes.

Steady State: a state in which an equilibrium has been achieved.

Stochastic: random or probabilistic but whose overall distribution follows some pattern; refers to patterns and cycles of flooding, and to cycles of population disturbance and fluctuation.

Stream Frequency: measure of topographic texture based on the ratio of the number of stream segments per unit area of the basin.

Stream Gradient: the ratio of drop in a stream per unit distance (metres per kilometre). Govern river speed, and volume of potential sediment load. Changes in gradient result in changes in speed, and in sediment discharge.

Subaqueous/Subaerial Weakening: the capture and removal by water of riverbank material, either just above (subaerial) or just below (subaqueous) the waters surface. In tandem with hydrological pressure, wave pressure, and riverbank stability, is responsible for transforming riverbank conditions.

Surface and Subsurface Exchange Processes: the interaction between ground water and surface water processes.

Terp: a town built on a dike or terpen (see also terpen, geestgrond, and grachtenstad).

Terpen: an artificial hill of packed mud that clears the height of a tide (i.e. berm) (see also geestgrond, grachtenstad, and terp).

Thalweg: the line of maximum depth and velocity within a river.

Thermo-erosion: fast moving and sudden erosion into channels and gullies by water, combined with its thermal effect on frozen ground and controlled by snowmelt regime and summer precipitation.

Transgression Lineaments: striations that form where deposits have been carried away by the river as it overflows the bank at a certain point; the resulting braids create the distinctive pattern that identifies most meander systems.

Trophic Level: functional classification of organisms in a community according to feeding relationships; the first trophic level includes green plants; the second level includes herbivores, and so on.

Vertical and Lateral Hydrological Connectivity: connection across subsurface and surface boundaries within a river and on the adjacent bank. These connections between the simplest forms of life at the river's edge form the most basic unit of ecological growth and evolution. They are a necessary component of ongoing riverbank, riparian zone, and wetland health and viability. In more mature systems, these connections include all lifeforms that inhabit or depend upon the river's edge for food or habitat.

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