Site Analysis, Rehabilitation Options And Recommendations For Land At The Mouth Of The Current River

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Site Analysis, Rehabilitation Options and Recommendations for Lands at the Mouth of the Current River

By

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A MF report submitted in partial fulfilment of the requirements of the degree of Master of Forestry

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Advisor

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ABSTRACT

Sobering, C. S. 2000. Data Analysis, Site Planning, and Three Rehabilitation Options for Lands Located At the Mouth of the Current River. 149 pp. Advisor. Richard Clarke.

Key Words: Urban forestry, restoration ecology, land reclamation, forestry, ecology.

The land located at the mouth of the Current River in the City of Thunder Bay is derelict urban industrial land with significant social, ecological and recreational value to the community. A study of this land was undertaken to develop a number of restoration options, a description of the main restoration tools associated with each option and a recommendation on the preferred restoration option. It was not the intent of this study to develop a full rehabilitation prescription for the site. A systematic sampling procedure was undertaken on the site to obtain estimates of the land's soil and vegetative cover. The site was mapped using ARCINFO and GRASS GIS packages based upon historic mapping and air photo imagery. Estimates were obtained of soil characteristics and this data was subsequently compared to normal ranges of natural soils to determine if there were any limiting factors that would influence site restoration. Then an analysis of the floristic composition of the site was undertaken to determine the relative dominance of the plant species located onsite. Utilising the information gathered by site reconnaissance, public inquiries, reviewing community plans and analysing site samples a program and design were created for the site. Then four restoration approaches were described from a review of available literature; the horticultural model, naturalisation, ecological restoration and managing ecological succession. A site restoration framework was developed based upon the sample analysis. Ecological restoration was selected due to findings of high lead concentrations in the site's soils.

A CAUTION TO THE READER

This MF Report has been through a formal process of review and comment by the author's advisory committee.

It is made available for loan by the faculty for the purpose of advancing the practice of professional and scientific forestry.

The reader should realise that the opinions expressed in this document are the opinions and conclusions of the author and do not necessarily reflect the opinions of either the advisor, the committee, the faculty of the University.

INTRODUCTION

Thunder Bay, Ontario, also known as the Lakehead, is a city of approximately 120, 000 residents located on the northwest shore of Lake Superior. It's geographic location at the head of the St. Lawrence Seaway allowed it to become Canada's premier grain transportation hubs. See Figure 1 for a location map. The result of this historic development pattern was the coverage of most of its waterfront real estate by grain elevators, water-related manufacturing and processing and transportation corridors.

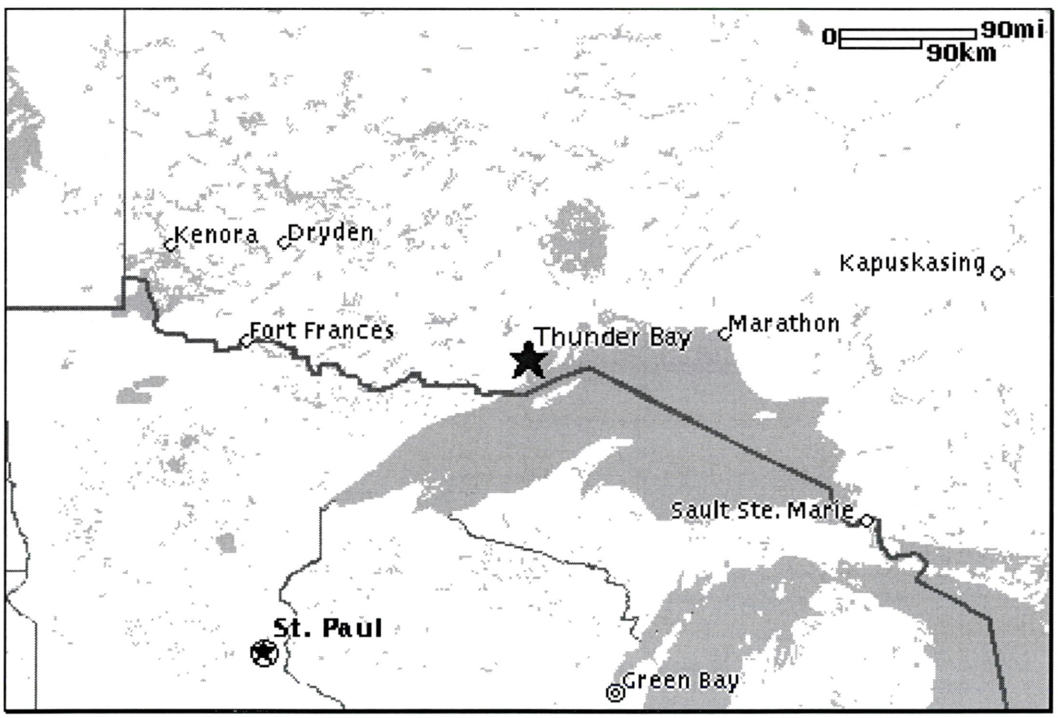


Figure 1: Thunder Bay Location Map.

Cities like Thunder Bay have undergone a gradual transition in the latter quarter of this century from centres of transportation, industry and manufacturing to post industrial service-based economies. The by-product of this trend was the abandonment of many former industrial lands that created a landscape of unsightly, unproductive, eyesores within the cities. This lead municipal politicians, city planners and urban foresters to focus on seeking creative solutions to the redevelopment and reclamation of these surplus lands to create new economic opportunities, restore degraded habitat and improve civic pride.

Thunder Bay has not been immune to this situation. A change in the flow of grain across the nation resulted in a decrease in the flow of grain and other materials through the port and a consequential shrinkage in the amount of infrastructure required. The end result of this process was the abandonment of large areas of industrial land on the City's harbour. While there are many negative aspects to this situation, these lands are an opportunity for the city to achieve a number of important community goals.

Encouraging greater and easier public access to the City's waterfront is a high priority for the City. Significant public funds have been invested to improve water quality, aquatic habitat and public recreational access to Lake Superior. The Marina Park development and the associated pedestrian overpass to the downtown north core is one such example of this.

The land located at the mouth of the Current River is a prime example of the decline in industrial activity on the City's waterfront. Formerly used to process local wood into pulp, the property now lies fallow. This land is an ideal candidate for restoration due to the following factors:

- the presence of an important urban fishery and fish spawning ground;
- the location of the land astride the Current River, an important urban watercourse, at its confluence with Lake Superior;
- its proximity to an existing linear park system on the Current River;
- its location within the working harbour;
- its public ownership; and
- its history.

It is apparent that the land located at the mouth of the Current River in the City of Thunder Bay has significant social, ecological and recreational value to the community. A study of this land was undertaken to develop a number of restoration options, a description of the main restoration tools associated with each option and a recommendation on the preferred restoration option. It was not the intent of this study to develop a full rehabilitation prescription for the site. This report contains an analysis of vegetative and soil data sampled from the property in the fall of 1997, a discussion of programming and site planning options for the development of the site for public use, a review of restoration options, and a recommendation as to which rehabilitation option best meets local needs.

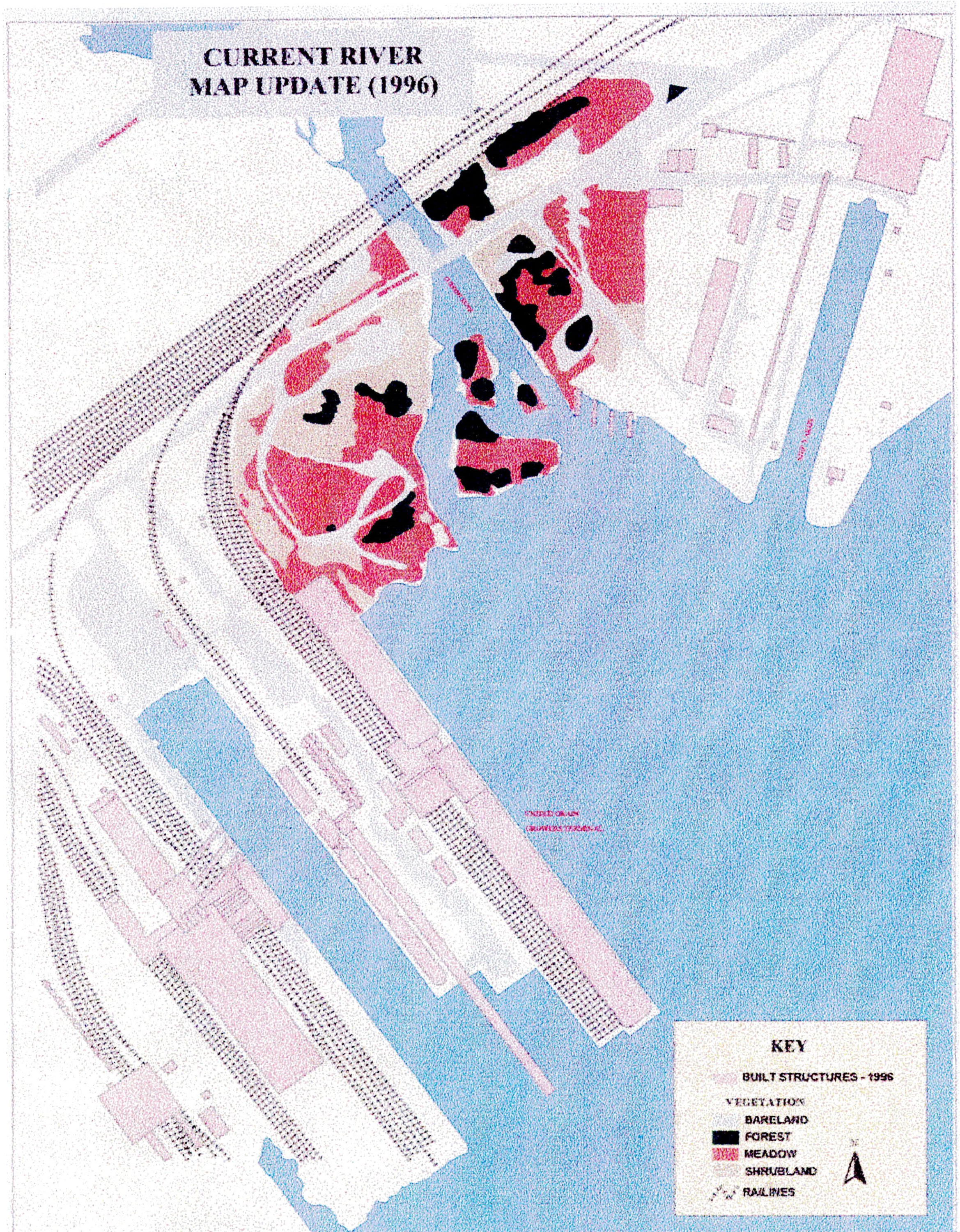
BACKGROUND

Site Location and Context

The site identified for rehabilitation is located in the northern portion of the City of Thunder Bay, Ontario at the confluence of the Current River and Lake Superior. It is a block of municipally owned derelict industrial land legally described as mining location #7 on the Herrick's Plan of 1866. Located on the City's working waterfront, the site is bounded to the north by the PASCOL shipyard, the south by the Port Arthur UGG terminal and the west by the Canadian Pacific Railway right-of-way (Thompson 1997). This is one of the few pieces of municipally owned land on the city's waterfront. See Figure 2 for a map of the site and surrounding area.

Physical Makeup

The Current River physically splits the 5.8 ha area of the study site into three distinctive parts: the north bank, the south bank and the midstream islands. Old shore cliffs separated by old abandoned beaches mark the landscape of this part of the City. The shore cliff located upstream from the site in Current River Park is perhaps the most prominent within the City (Sobering and Clarke 1996). Approximately 600 feet upstream from the site the river has been dammed creating Boulevard Lake. From the Boulevard Lake Dam the river drops about 40 feet as it makes it way to Lake Superior. The bedrock underlying the area is diabase, which is characterised by a large number of cracks or joints. These cracks cause the rectangular shaped blocky structure of the stone which gives the bed of the Current River its characteristic stepped form (Sobering and Clarke 1996).


CURRENT RIVER
MAP UPDATE (1996)
KEY
BUILT STRUCTURES - 1996
VEGETATION
BARELAND
FOREST
MEADOW
SHRUBLAND
RAILINES

Site History

The first reference to the site in the Herrick survey of 1866 is its sale by the Crown as part of a larger 171 acre block to one Thomas Morland in 1867. Shortly after its sale the first docks on Thunder Bay were constructed along this piece of shoreline in 1868 (Poling, 1996). Thirty years later the Canadian Pacific Railway (CPR) made its first purchase of land in the area and by 1912 the corporation constructed the first of the rail lines that run along the lakeshore. These were subsequently moved further from the lake in 1962. In July of 1920 the Thunder Bay Pulp and Paper Company purchased a portion of the subject area and constructed its pulp mill (Thompson 1997). A pipeline was constructed across the Current River to connect this mill to a paper plant located to the northeast. Two of its supporting concrete piers can be observed in the river to this day.

A fish hatchery, residence and outbuildings were constructed on the north bank of the river during the intervening years. This facility was dismantled during the 1960's (Iwachewski 1996). This bank of the river also contained a hydroelectric powerhouse (Thompson 1997) which was reported to supply electricity to the former pulp mill. As part of the power house development a concrete retaining wall was installed along the north bank of the Current River and a wooden stave/hoop pipeline was installed to supply the generating station with water from Boulevard Lake. The track of this pipeline is still visible on 1940's vintage air photos of the site and some artefacts from this structure remain onsite. The pulp mill ceased operations in the early 1970's, but the owner of the period, Abitibi, continued to utilise the building for office space. It was during this period that the land was sold to the City of Thunder Bay (Thompson 1997). In 1974 the city leased the property to Robert W. Morton who operated a boat yard until the mill building was torn down (Clarke 1999). Little formal activity has occurred in this area in the intervening years. In 1984 Public Works Canada built a concrete boat launch and docks at the foot of Fisherman's road for commercial fishing.

Natural Resources

The site is also home to "...the only known spawning site of walleye in Thunder Bay Harbour... " (Bray 1997). In the past the walleye population at the mouth of the Current River was "abundant enough to serve as a source for stocking inland lakes and neighbouring bays in Lake Superior" (Bray 1997). In 1991, without disturbing existing spawning sites, clean gravel, cobble and boulders were placed in three different areas at the mouth of the river to increase the amount of suitable spawning habitat (Bray 1997). In addition fish access to the upper reaches of the river has been made possible by the installation a fish ladder on the Boulevard Lake dam and the creation of resting pools in the bedrock of the dam's spillway (Iwachewski 1995).

Planning Context/Community Goals

The history of land development is marked by many acclaimed projects which for a variety of reasons became failures. For the most part successful developments meet basic community needs and are based on a strong community vision. There are a number of ways that a community can go about expressing its vision. One is the use of community plans. The Thunder Bay community plan is one of the main tools for describing the City's long term growth and development goals and strategies. In this plan the subject area is covered by three different zonings which correspond closely to the three areas into which the land is physically divided. Figure 2 shows that the south bank of the subject property is zoned Open Space (OS), the riverbed, which includes the island group, is zoned as Hazard Land (HL) and the northern bank of the river is designated as Harbour Related Industrial (HRI).

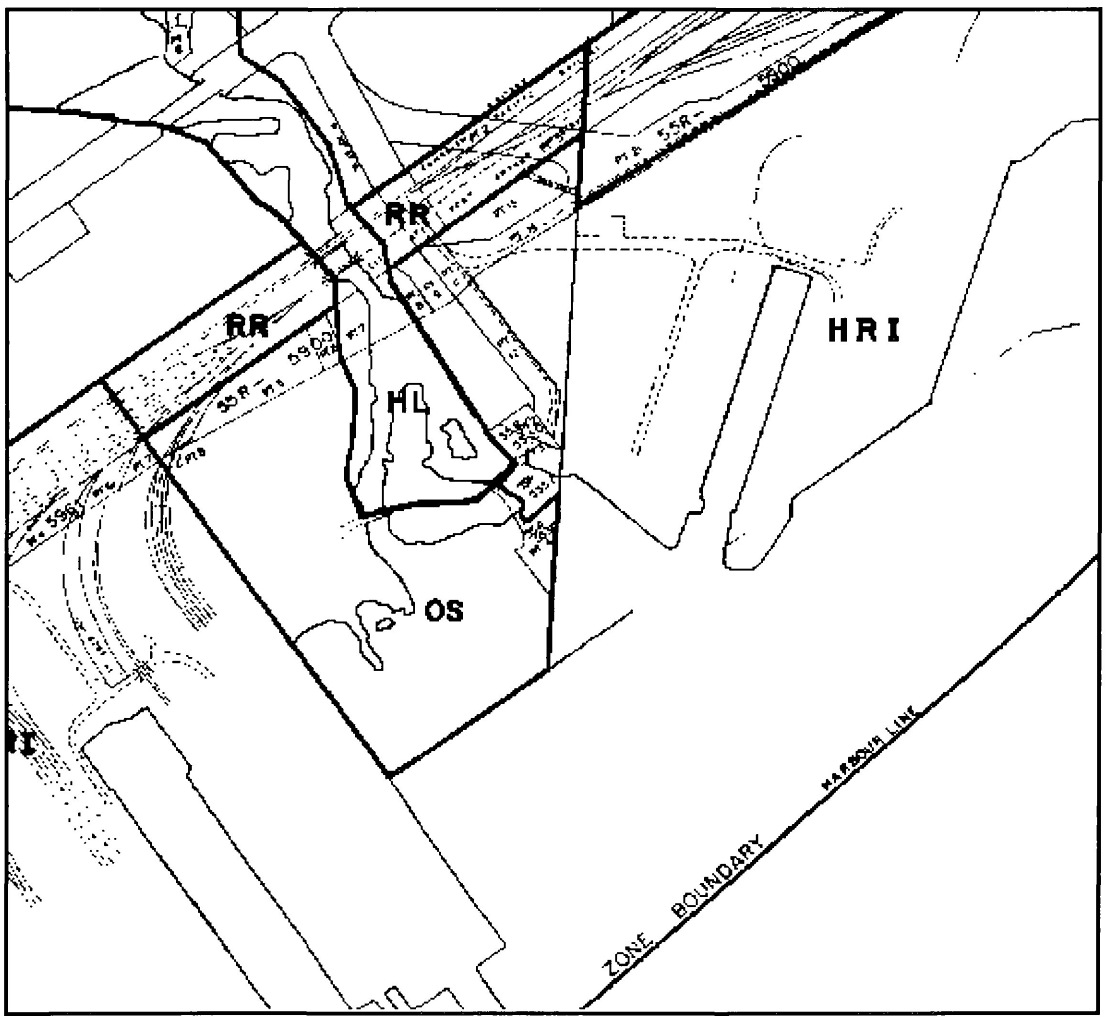


Figure 3: Zoning Map For Subject Area.

Community plans are not the only way for a city to express its development policies and goals. Professional facilitators can lead public visioning processes to develop strategic plans for a wide range of community issues. In response to funding under the Northern Ontario Heritage Fund the City of Thunder Bay retained a multidisciplinary team to facilitate the development of a long-term vision for the waterfront and a three-year development plan. The goal of this process was to transform available waterfront lands by stimulating commercial and tourism development and establishing major new destination attractions with the intent of developing the waterfront as an international tourist destination.

The team used a consensus-building approach to allow all waterfront stakeholders - government staff, landowners, interest groups, business operators, Council and residents - to participate in decision making at workshops in each stage of the process (The Planning Partnership 1998). The outcome of this process was the development of a number of planning and design principles. The following is a selection of those principles, listed by category, which have bearing upon the restoration options identified later in the report.

Access:

- Enhance views to the waterfront;
- Provide continuous public access along the waterfront, sometimes at the water's edge;
- Connect waterfront to the City's urban cores;

- Provide safe truck access to industries, while improving access on roads by other vehicles

Diversity:

- Provide a diversity of nodes, linkages and habitats;
- Provide for all land uses on the waterfront;
- Recognise and highlight the cultural importance of the waterfront;
- Create a high quality urban and natural experience.

Natural Environment:

- Connect the waterfront with ”greenways” - linkages, natural corridors;
- Establish an “environment first” vision;
- Maintain and enhance the integrity of the water’s edge ecosystems;
- Continue to remediate contaminated soil and water and rehabilitate degraded landscapes;
- Continue to enhance fisheries habitat.

Tourist Destination Attraction:

- Celebrate the inherent qualities of the city (eg its heritage, culture, forests, geology, and climate) (The Planning Partnership 1998).

In order for these design principles to be applied to the development of a master plan, they were expressed as elemental principles. Five elemental principles were identified:

- provision of continuous public access along the full length of the waterfront;
- redevelopment within the context of an active working industrial port;
- development of the waterfront in a sustainable manner;
- extension of the urban cores to the waters edge; and
- development of the north waterfront district as the primary destination attraction.

The first elemental principle, public access, supports the careful design of safe routes for pedestrians and cyclists through the waterfront. Primarily these routes must run throughout the waterfront and along the water's edge, where possible; however, they do not have to be within the road right-of-way. On a city wide basis centres of activity along the waterfront should be linked to residential communities, schools, Confederation College, Lakehead University, major parks and other community facilities along a series of greenways that follow the various water courses running through the community (The Planning Partnership 1998). One of the key pieces of access infrastructure within the waterfront will be the waterfront drive. The primary design ambition for this basic component of the Waterfront Plan is to develop a parkway-like waterfront drive with a curb, continuous green boulevard for street trees, unique street lighting, signage and banners, with a sidewalk and cycling lane where appropriate (The Planning Partnership 1998).

The implication of the second elemental principle, redevelopment within the context of a working port, is that access and opportunities for viewing industrial activities in the port must be carefully planned to ensure industrial activities are not compromised. These industries have a very important role to play in contributing to the appeal of the new waterfront districts. Furthermore, views of grain elevators, timber operations and shipping from Waterfront Drive could have an enormous appeal to tourists (The Planning Partnership 1998).

The third elemental principle for master planning is sustainable development. The implications of this principle is that the environmental enhancement initiatives should be integrated into any redevelopment. The master plan makes recommendations on the actions that must be undertaken to achieve these goals. The following are the recommendations with relevance to this project:

- continue to implement projects to naturalise watercourses as green linkages to the waterfront, with public access provided where possible;
- continue to enhance woodlots, riparian vegetation communities and fragments of the natural shoreline;
- continue to enhance and diversify aquatic habitat along the watercourses and lake shoreline;

- continue to re-establish marshes in the harbour, particularly in districts planned for urban uses (The Planning Partnership 1998).

In their report the planning team discussed the environmental framework for redevelopment on the harbour. It was noted that the north waterfront district presents a range of opportunities for habitat enhancement, wetland creation, water quality improvement and interpretation. They further suggest that the existing and ongoing initiatives of the Lake Superior Programs Office, such as the Northern Wood site remediation, Sanctuary Island and habitat enhancement projects on McVicar Creek and the Current River, provide the basis for the environmental framework for this area of the waterfront. They envision these leading-edge environmental projects as the fundamental programmatic components of the Science North attraction (The Planning Partnership 1998).

Specific mention is also made of the project site in the report. The authors suggest that the shoreline and inland area around the fishing pier at the mouth of the Current River should be upgraded to enhance the habitat and the landscape appeal of this public waterside location as part of the sustainable development of the waterfront (The Planning Partnership 1998).

From the previous review of the community visioning process it is apparent that there is strong public support for the restoration of the project site and its use for public access to the waterfront.

METHODOLOGY

This report is the product of a six-stage process. These stages consist of Literature Review, Site Assessment, Public Input, Data Analysis, Site Programming and Design, Restoration Methodologies, and Restoration Recommendations. The historical context of the site was investigated by Eric Thompson a HBScF graduate of Lakehead University's Forestry Faculty. The author in consultation with his advisors undertook the remainder of the work.

LITERATURE REVIEW

The first step in this process consisted of a wide ranging review of literature covering land assessment, land restoration, ecology; urban forest and other soils, sampling and analysis methods for soil and vegetation, community plans and public policy and visioning reports. In addition, historical information was provided by Thompson (1997) through his undergraduate thesis entitled Historic Assessment on the Industrial Land at the Mouth of the Current River, the City of Thunder Bay's community plan and the Planning Partnership's report The Next Wave: Charting a Course for Thunder Bay's Waterfront (1998).

SITE ASSESSMENT

The second step in this process was to develop a site assessment plan. This site assessment methodology is predominantly based upon the CSA Z768-94 Phase 1 Environmental Site Assessment Standard. This standard was modified, enhanced and expanded by borrowing from disturbed land restoration literature & sampling theory. The following is a brief overview of the method employed in this process. A more detailed explanation is contained in Site Assessment Methodology For Urban Forest Restoration Planning And A Soil And Vegetation Sampling Plan For Land At The Mouth Of The Current River (Sobering and Clark 1997).

In general the site assessment consisted of multiple site reconnaissance visits, a historical review and sampling. In September of 1996 two reconnaissance visits were made to the site to collect general site information. One further site visit was made with Lucie Lavoie of Thunder Bay 2002 during the winter of 1996/97 to analyse potential links to other public lands within the city. Notes taken during these site visits recorded general information on vegetation cover, soils, topography, human artefacts, and site use. These visits provided much useful information and gave many clues to the past use of the property and the current state.

Thompson (1997) completed the historical review of the property. He collected his data by combing historical records and interviewing individuals who held past associations with the land in question.

The final step in the site analysis was to develop and implement a soil and vegetative sampling plan. The decision was made to take soil and vegetation samples because these two parts of the ecosystem can tell much about the potential of a site for restoration and what species/plant communities may be suitable for restoration works. For details of the sampling plan see Sobering & Clarke (1996).

PUBLIC INPUT

Views of interested parties within the local community were sought concomitant with the development of the sampling plan. This information was obtained in two ways. The first was via a direct mailing to those government agencies who had a jurisdictional interest in the land and to those interest groups whose particular focus was felt to be affected by any activities/change of status of the subject land. A form letter was forwarded to the following groups and organisations: Ontario Ministry of Environment (OMNR), Public Works Canada, Canada Coast Guard, Thunder Bay Harbour Commission, North Shore of Lake Superior Remedial Action Plan Public Advisory Committee, Steelhead and Salmon Association, Field Naturalists, Commercial Fishers, PASCOL, & United Grain Growers Ltd. In addition a number of informal interviews were held with staff representatives of The City of Thunder Bay's Planning and Parks Departments, Thunder Bay 2002, and the Ontario Ministry of Natural Resources (MNR). The findings of this process are compiled in a report titled <u>Opinions of Community Interest Groups Concerning the Proposed Restoration of Land Located at the Mouth of the Current River</u> (Sobering 1997).

A third and extremely valuable source of public input was from a public visioning report prepared by the City of Thunder Bay in response to the potential for funding under the Northern Ontario Heritage Fund. This report was the produced by a multidisciplinary team retained by the City of Thunder Bay and charged with developing a long term vision and a three year plan to begin transforming available waterfront lands. The details of this work are described in The Next Wave: Planning a course for Thunder Bay's Waterfront.

DATA ANALYSIS

The soil samples were analysed for a variety of physical and chemical characteristics: pH, infiltration, bulk density, cation exchange capacity (CEC), nitrogen (N), phosphorous (P), salinity, texture, common cations, organic matter content, and moisture content. Main vegetation types were mapped and described, a community floristic analysis was conducted on the herbaceous and shrub stratums.

SITE PROGRAMMING & DESIGN

The next step in the process was to develop a site program for the subject property. The site's program attempts to answer both the broader question of what general activities should be actively encouraged and accommodated on the site (e.g. fishing, bird watching, picnicking, etc.) as well as the more mundane details required to realise the broader vision (eg access, parking, circulation, seating, sewage disposal, shelters, toilet facilities, etc.).

Once the programming was completed, the next step was to complete a site design. The site design melds the program and landscape restoration into one final vision for the property. It is here that questions concerning habitat elements were addressed.

REHABILITATION RECOMMENDATIONS

The final step in the process is to make recommendations how the City should rehabilitate the site. These recommendations are based on the results of the site analysis and restoration literature review materials in the preceding portions of the report.

Restoration aspects include soil amelioration requirements, regeneration techniques, the schedule of works, and post restoration maintenance requirements.

DATA ANALYSIS

Soil samples were analysed at Lakehead University's Faculty of Forestry soils laboratory and Instrumentation Laboratory. Analysis methods are described in detail by Sobering (1997).

The sampling plan for the project is described in Site Assessment Methodology For Urban Forest Restoration Planning And A Soil And Vegetation Sampling Plan For Land At The Mouth Of The Current River (Sobering and Clarke 1997). As with all sampling plans a number of adjustments were made in the field to address unforeseen circumstances. In particular a number of proposed sample plots were dropped during the field sampling as the random selection of the point of commencement resulted in plots being located in areas with no soil or vegetation (i.e., paved roads, bedrock). The vegetation was sampled for species composition and abundance using fixed area plots. Soil and vegetative samples were taken at every plot. Vegetative samples were broken down into three separate subgroups: herb, shrub, and tree stratums. Due to the discovery during sampling that the site coverage of the tree strata was limited in area fragmented and composed of both native and ornamental species, the tree strata data was dropped from the analysis.

It should also be noted that the sampling strategy failed to record the presence of a number of other species of trees. Ornamental plantings of American elm *(Ulmus* *americana* Mill.), ornamental crab apples (*Malus spp.*), jack pine (*Pinus banksiana* Lamb.), hybrid roses (*Rosa spp.*) and lilac (*Syringia communis*) as well as the natural occurrence of eastern white cedar (*Thuja occidentalis* L.), red pine (*Pinus resinosa* Ait.) and paper birch (*Betula papyrifera* Marsh.) were not reflected in the samples while their presence on site was noted during the initial site assessment. This led to the conclusion that the herbaceous and shrub data provided a more accurate reflection of the natural processes on the site and would consequently be of more value in making management decisions. Consequently the tree strata's data were dropped from the vegetative analysis.

SOIL ANALYSIS

When attempting to return a degraded site to a productive state the land restorer is mainly interested in those characteristics of a site's soil that could have a negative impact on the ability of a healthy, self sustaining community of plants to regenerate on the land. Consequently, the restorer must conduct a detailed analysis of the physical and chemical characteristics of the overburden material present on the site (Michaud 1981). Characteristics that are of interest to the restorer are pH, bulk density, CEC, texture, organic matter content and soil nutrient status.

The soil nutrient status of the landscape is one of the key soil characteristics with respect to plant establishment success. Elements that are essential for plant life include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S). These elements, the macronutrients, are required in fairly large concentrations. Also essential, although in minute concentrations, are the micronutrients. These include manganese (Mn), iron (Fe), boron (B), zinc (Zn), copper (Cu), chlorine (Cl), and molybdenum (Mo). There are several other elements that are not necessary for plant survival but that are beneficial for healthy plants. The quantity of each nutrient needed for healthy growth varies with the plant species (Michaud 1981). It has been suggested that 12 other trace elements, arsenic (As), chromium (Cr), cobalt (Co), fluorine (F), iodine (I), lead (Pb), lithium (Li), nickel (Na), selenium (Se), silicon (Si), tin (Sn) and vanadium (V), are also beneficial to plant growth (Pais et al 1997). For the purposes of this study values for the following elements were obtained for soil samples taken from the subject property: N, P, K, Ca, Mg, Na, Al, Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn.

In addition to the status of nutrients and elements in the soil a number of physical and chemical characteristics of the soil were analysed.

To use the soil data effectively the values obtained must be compared to some measure of the normal threshold or range characteristic of healthy plant growth. Ideally the restorer would compare site results to baseline data collected from the site prior to disturbance; however this is frequently impossible as restoration is often done years after a debilitating land use has taken place and no baseline data are available. Such is the case with the Current River site. The next best option for the restorer would be to obtain baseline data from a site within the region that is similar to the pre-disturbance condition of the area to be restored or similar to the desired post restoration condition of the site if no record of the original condition of the site is available. Unfortunately, a search of the available literature failed to locate any studies of the Thunder Bay area that could be used for this purpose. The third, and least favourable option, is to compare the site data to a set of toxic ranges or normal ranges for typical soils based on studies, experiments, and professional experience. In the absence of other sources of baseline data this was the method selected for this project.

The toxic concentration of a soil born element is generally viewed as the concentration at which detrimental effects to plant growth and health occur. Several authors have set suspect levels for the onset of toxicity or described the range of elements for "normal" soils. These normals reveal that the range of concentrations at which toxicity occurs varies greatly. This is due to the fact that the availability and toxic effect of any one element is affected by several properties of the soil and on the concentrations of other elements (Michaud 1981). Michaud (1981) suggests that these levels range widely in natural soils and that the concentration in disturbed areas should be compared to those found in soils in the same area. As mentioned previously this was not possible in this case.

Element	Range Low	Range High	Common Low	Common High	Tolerance
Al*	1	10	n/a	n/a	n/a
Ca	175	900	n/a	n/a	n/a
Cd	0.01	1	0.1	1	5
Co	1	50	1	10	50
Cr	1	100	10	50	100
Cu	2	100	5	20	100
Fe	5,000	50,000	n/a	n/a	n/a
K	50	100	n/a	n/a	n/a
Mg	78	975	n/a	n/a	n/a
Mn*	15	60	n/a	n/a	n/a
N	15	75	n/a	n/a	n/a
Ni	1	100	10	50	100
P	9	15	n/a	n/a	n/a
Pb	0.1	10	0.1	5	100
Zn	10	300	10	50	300
CEC (meq/100g)	6	300	n/a	n/a	n/a
SAR	4	12	n/a	n/a	n/a
OM (%)	0.4	10	n/a	n/a	n/a
BD	n/a	1.65	n/a	n/a	n/a
pH	5	8	n/a	n/a	n/a

Table 1: Range of Common Soil Elements, Nutrients and Characteristics (after Michaud 1981, and Pais 1997).

There are no simple limiting soil parameters recognised where vegetative growth becomes difficult or impossible due to toxicity. Table lists the range of values where a physical or chemical characteristic of a soil may affect vegetative growth. These values were gleaned from a number of sources and reflect a best estimate based on current science. The readings for the Current River data will be compared to these levels or ranges to determine if they will act as limiting factors to the re-vegetation of the site.

In temperate regions surface soils normally contain 0.4-10% organic matter (Michaud 1981). Figure 4 is a graph of the organic matter content of the Current River soil samples expressed in percent plotted against the normal organic range in temperate mineral soils from Table 1. This graph indicates that most of the samples have organic matter contents that fall well within the normal range. However, the graph does show that a number of the soil samples have an organic matter content that is significantly higher than that expected in a normal mineral soil. Plots 8, 9 & 13 correspond with the portion of the site covered by a bark pile left over from the pulp mill's operation, hence the reason for their high readings. Plots 24 & 25 were located in a marshy area located on the lakeshore. The high organic content found in these plots may be due to an absence of decomposers on site. This could be due to the skeletal nature of the site's soils or the area's high water table creating anaerobic conditions that are unfavourable to decomposer activity. During future sampling work the site should be stratified according to these soil types/site conditions.

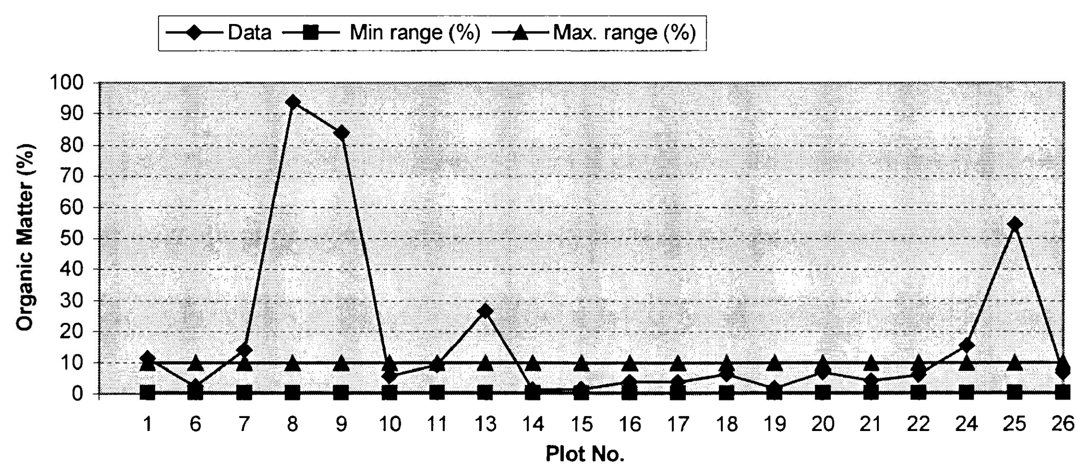


Figure 4: Graph of Current River organic matter readings (%) with the range for normal soils.

The density of the soil found on a site can have a significant impact on the ability of plants to thrive. Soil density is commonly estimated by the bulk density calculation which describes "...the weight of a given volume of soil...as grams per cubic centimetre of soil" (Lyle 1987). The general rule of thumb is that, as a soil becomes compacted, its bulk density increases. Since soil compaction is essentially a reduction or loss of pore space within a soil, compacted soils tend to experience a reduced ability to move water and air through the soil, a decreased moisture holding capacity, and a restriction on the penetration of plant roots (Lyle 1987).

A "normal" soil has a particle density of approximately 2.65 g/cm^3 and a bulk density of around 1.5 g/cm^3 (Michaud 1981). Bulk density varies according to the particle size distribution within a particular soil. It has been found that normal plant root growth is restricted as bulk density increases beyond 1.5 g/cm^3 for fine textured (clay and silt) soils and beyond 1.7 g/cm^3 in coarse textured (sandy) soils (Lyle1987). As the soils sampled at the project site were predominantly sandy in texture, the 1.7 g/cm^3 root penetration limiting value will be used here for comparison. Figure 5 is a graph of the bulk density of Current River soil samples plotted with this bulk density limit. It indicates that none of the samples possessed a bulk density greater than 1.7 g/cm^3 suggesting that soil compaction is not a concern for our purposes.

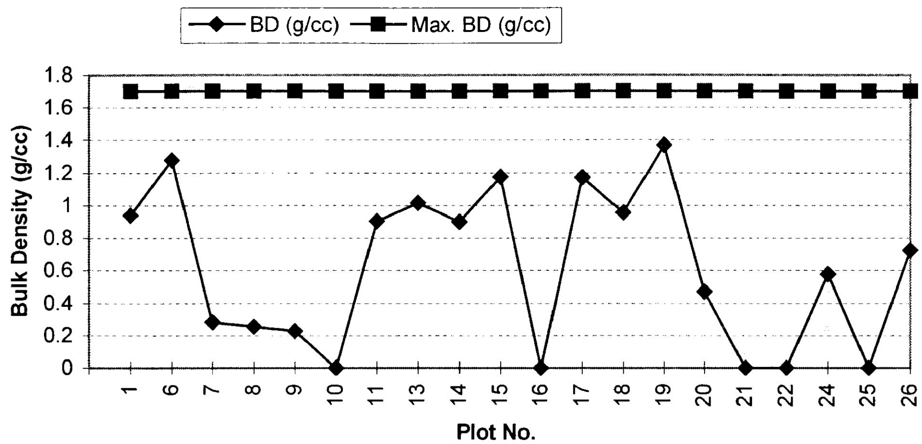


Figure 5: Current River bulk density readings with the maximum density for root growth.

Soil pH is a measure of soil acidity or alkalinity (the concentration of hydrogen ions (H^+) in the soil solution). As a rule, soils that are acidic tend to have a pH below 5, and those which are alkaline, a pH above 8 (Bradshaw et al 1980).

The pH of a soil can significantly affect plant growth for a number of reasons; one reason is its impact on soil microflora and fauna. Studies have found that "When the soil pH decreases to approximately 5.5, both bacterial and actinomycetes activity decreases significantly. This decrease in activity is important for such things as nitrogen fixation by legumes and other nitrogen fixing organisms. The activity of fungi present in the soil is also affected by soil pH. Fungi are not greatly affected by soil pH itself and the decrease in activity associated with pH is an indirect affect resulting from the competition of increased bacterial and actinomycetes activity" (Lyle 1987).

Soil pH also can create what are termed secondary effects. Secondary effects can be illustrated by the finding that plants grown in water culture experiments can tolerate wide ranges of acidity or alkalinity; whereas, the same species grown in soils at the same pH's exhibit a marked difference in observed growth. These differences are a result of secondary causes or effects. One specific example of a secondary effect in alkaline soils (pH greater than 8) is that the micronutrients iron, manganese and boron become difficult for the plant to absorb. Another secondary effect of high pH is a reduction in the availability of phosphate to plants. This occurs because the high pH causes the available phosphorous to change into insoluble compounds which plants cannot use (Bradshaw et al 1980). In the case of soils with excessive acidity the secondary effects include calcium deficiency and an excess of aluminium and manganese. While these latter two elements are present in most soils, they are usually found in a form unavailable to plants; however, when the pH drops below 4-5 they become more soluble and can have direct toxic effects (Bradshaw et al 1980).

Lyle (1987) advises that the range of pH for most natural soils is between 4.0 and 8.5 and that the majority of agricultural crops grow best between a pH of 6.0 and 7.0. For the most part a low soil pH reading is due to low soil calcium content, high sulphur content or toxic amounts of aluminium (Lyle 1987). The pH readings for the Current River samples have been plotted in Figure 6 with Lyle's maximum and minimum pH range for natural soils. This graph indicates that soil in the project site are well within the "normal" parameters for plant growth and implies that soil pH is not a limiting factor for plant growth on the site.

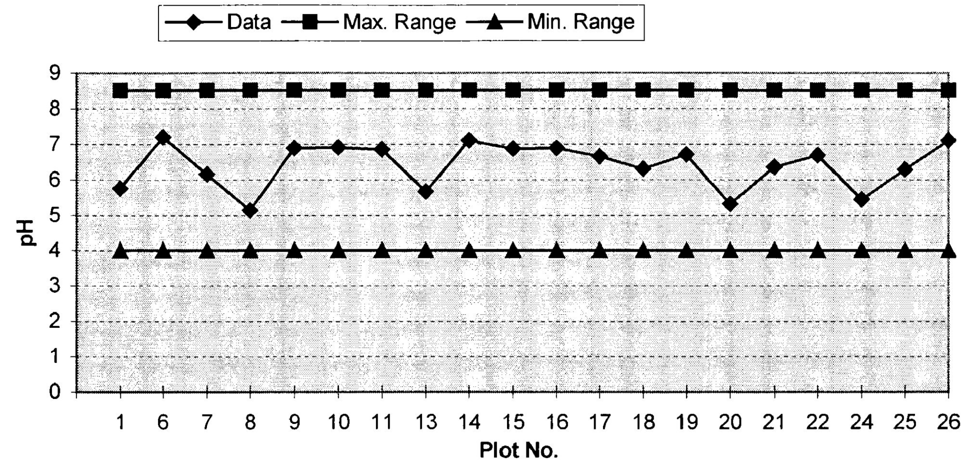


Figure 6: Graph of Current River pH readings plotted with the common range.

The presence of salt in soils at sufficiently high levels can be toxic to plants. It has been reported that 1,000 ppm of salt (0.1%) in silt loams and 500 ppm of salt (0.05%) in coarse loamy sands is toxic to plant growth (Michaud 1981). A soil is described as sodic when it contains an excess of exchangeable sodium or a predominance of sodium ions in solution. The percentage of sodium ions that are active in exchange reactions is related to the concentrations of calcium and magnesium. This relationship, the sodium adsorption ratio (SAR), is expressed as

$$\mathrm{SAR} = \frac{Na}{\left(\frac{Ca + Mg}{2}\right)^{1/2}}$$

where the concentration of Na, Ca and Mg are expressed in milliequivalents/litre of saturated soil extract (Michaud 1981). In Figure 7 the SAR for each Current River sample plot is graphed with the common SAR for fertile soils and agricultural. This figure indicates that the SAR values for the project area are significantly lower than the norms. Since Michaud advises that salinity problems only occur where SAR > 12, this is obviously not a concern for the subject site.

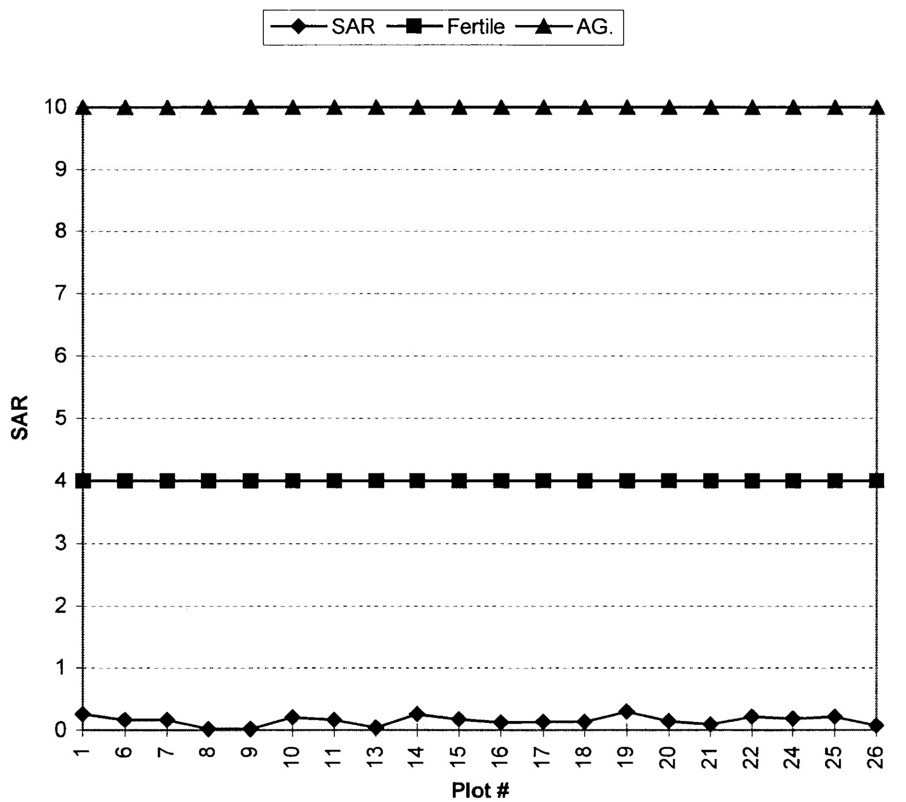


Figure 7: Current River SAR values with common value for agricultural and fertile soils.

The cation exchange capacity (CEC) is an important index of the nutrient status of a material. It is an indirect measure of the surface area available for water and nutrient retention and, therefore, the ability of the soil to hold available nutrients.

Consequently, where the CEC is low, soil nutrients are lost through leaching. Soil CEC also influences a soil's ability to buffer or resist changes in pH and thus the lime requirement for neutralisation. A normal sandy soil has a CEC of around 6 meq./100g, whereas an organic material or clay may have a CEC as high as 300 meq./100g. In general, the higher the CEC, the more potentially fertile the soil (Michaud 1981). The CEC values for the Current River soil samples are plotted with the norm for a sandy soil in Figure 8. This graph indicates that, for the most part, the CEC at the site is substantially lower than that expected for a normal sandy soil. The one plot with a CEC within the normal range also has a high organic matter content. Since CEC appears to vary with organic material content those deficient portions of the site can have their cation exchange capacity enhanced by the application of organic matter.

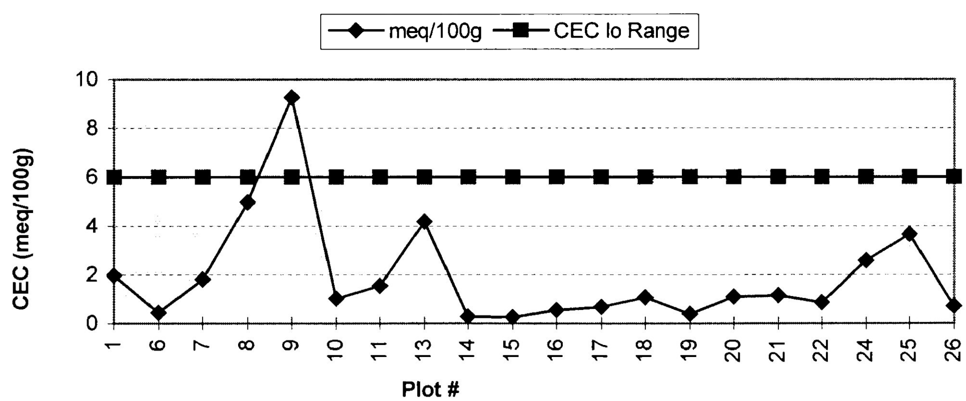


Figure 8: Current River CEC readings (meq/100g) with average value for sandy soils.

Nitrogen is the most important nutritional factor for plant growth. This claim is based on a "...a strong body of evidence demonstrating that N-availability is the primary limiting nutritional factor in northern temperate glaciated soils in the USSR, Scandinavia, North America and also in the non-glaciated cascade and coast ranges in Washington and Oregon" (Weetman 1982). Nitrogen fixation by legumes is maximised if the soil is at a pH of 5.0 or higher for bacteria will not penetrate many of the legume roots at soil pH below this threshold (Lyle 1987). Figure 9 is a graph of the Current River N readings plotted with the range for normal soils suggested by Michaud. This figure shows that the site's soil nitrogen levels are predominantly deficient. Those samples with nitrogen readings within the range generally correspond to the soils with high organic matter contents. Because of nitrogen's key role in plant growth additions of organic or inorganic nitrogen to the soil may have beneficial effects on plant growth.

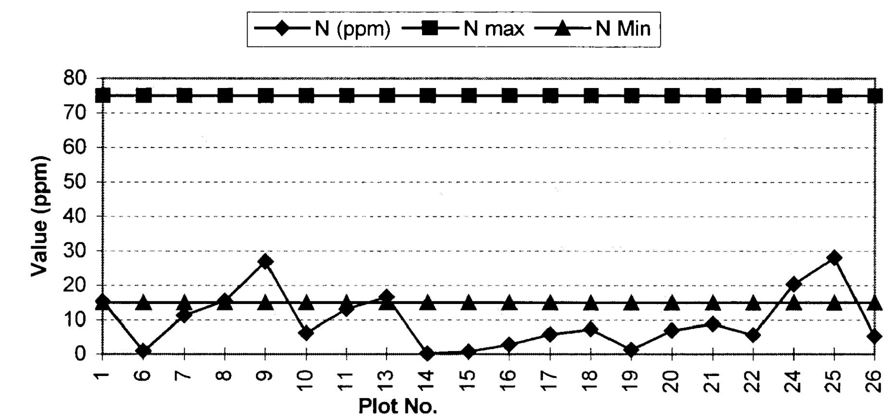


Figure 9: Current River Nitrogen readings (ppm) plotted with the range of readings for normal soils.

Magnesium deficiencies are found in soils that are acid, sandy to loamy sand in texture, with low organic matter content, and low total CEC and base saturation. In general soils of alluvial, glacio-fluvial, and blown sand origins are more likely to show Mg deficiencies than soils of glacial till origin. The balance between the levels of K, Mg and Ca within the soil may also be important as calcium and magnesium compete for the same carrier sites and excesses of one may induce or aggravate deficiencies of another. The ratio of exchangeable Ca:Mg is often examined and normally ranges from approximately 3:1 to 5:1, although values outside of this range do not necessarily mean a deficiency exists. Soils with less than 10-12 ppm of extractable Mg may be deficient (Ballard 1986). Figure 10 is a graph of the Current River Mg readings plotted with Michaud's (1981) range for normal soils. This graph indicates that the Mg content of the study site's soil is predominantly within the normal range except for a few instances where it is slightly deficient. These deficient samples were taken from the bark pile.

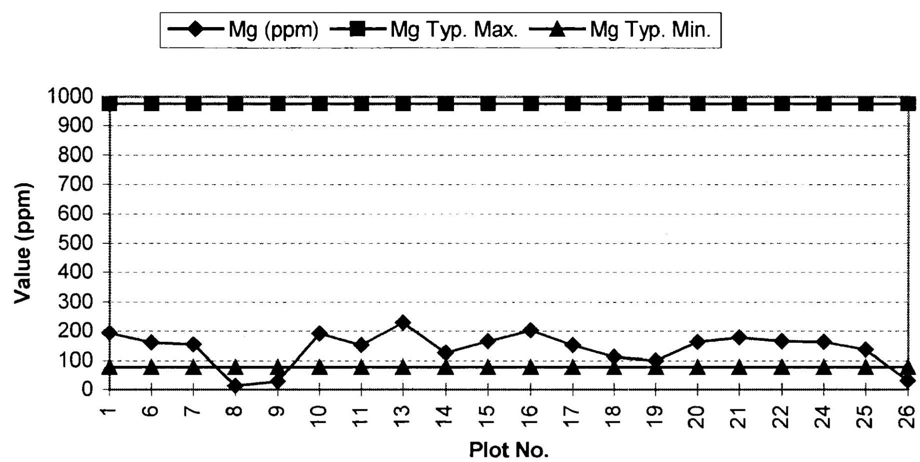


Figure 10: Current River magnesium readings (ppm) with normal range.

Manganese is thought to be essential for plant nutrition. Plant sensitivity to Mn varies considerably and those plants that are sensitive to toxicity are equally sensitive to deficiency. Alternately, some species can accumulate high levels of Mn without suffering any detrimental effects. Manganese availability decreases with increasing soil pH; the general rule-of-thumb is that Mn deficiency will occur at a soil pH $\geq$ 7.5 and toxicity at a soil pH $\leq$ 5.5. Manganese availability is also reduced by low soil temperatures and with increasing soil organic matter content. Furthermore, the manganese status of a plant can be significantly influenced by its relationship to other elements; this is primarily a concern with iron although phosphorous, calcium, magnesium and silicon will affect Mn status as well (Pais et al 1997). Figure 11 is a graph of the Mn readings for each sample plotted against a suggested range for Mn toxicity. The graph suggests that Mn toxicity is unlikely to be a problem on the site except in the instance of plot #1.

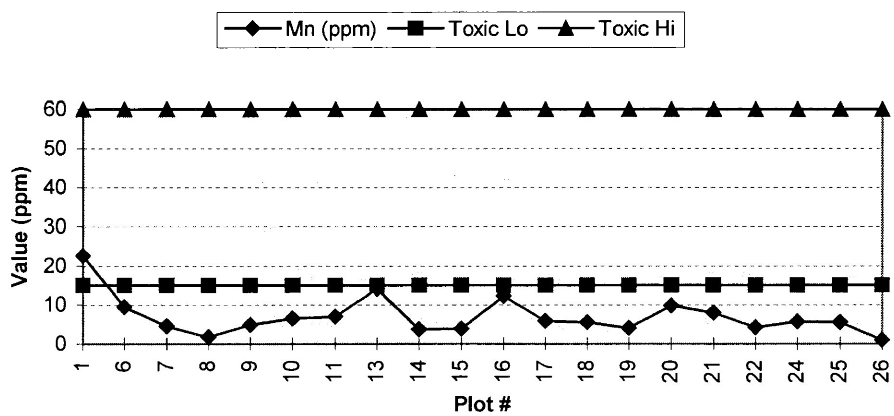


Figure 11: Current River manganese readings with toxic range.

Literature on phosphorous availability and nutrition in plants describes factors that should be taken into consideration when determining if phosphorous is deficient. The first factor is that soil phosphorous is usually found in forms that are unavailable to plant roots due to their high relative insolubility in water. "In acid soils insoluble iron and aluminium phosphate compounds are formed, and in alkaline soils insoluble calcium phosphate compounds are formed" (Lyle 1987). Phosphorous will likely be at its maximum availability to plants at a pH of about 6.0 as it is least likely to form insoluble compounds with aluminium and iron or calcium here (Lyle 1987). The advantage of this situation is that other plant nutrients, if present in adequate amounts, should be satisfactorily available when soil pH is suitably adjusted for phosphorous availability (Michaud 1981). However, using soil analysis to identify phosphorous deficient sites is quite difficult because phosphorus nutrition is dependent on more than phosphate availability. The kind and vigour of mycorrhizal populations associated with roots as well as the soil's nitrogen concentration can affect both uptake and availability of P (Ballard et al, 1986). "In general, the restorer can assume that if extractable P is high, P availability is unlikely to be the cause of any observed deficiencies; however, if extractable P is low (< 2ppm) it is difficult for precise interpretations to be made without more knowledge of the factors controlling availability and uptake..." (Ballard et al 1986). Figure 12 is a graph of the sample phosphorous readings plotted with the range for a normal soil and Ballard's (1986) range of concern. The graph shows that the phosphorous levels on the site is consistently well below what is considered "normal", but that they are for the most part above what Ballard considers the threshold of concern. The lowest readings are found in the samples taken from the bark pile. While Ballard's figures were developed for British Columbian forests, they are likely more accurate than the normal ranges which were developed from a wide range of agricultural and forest soils in temperate climates.

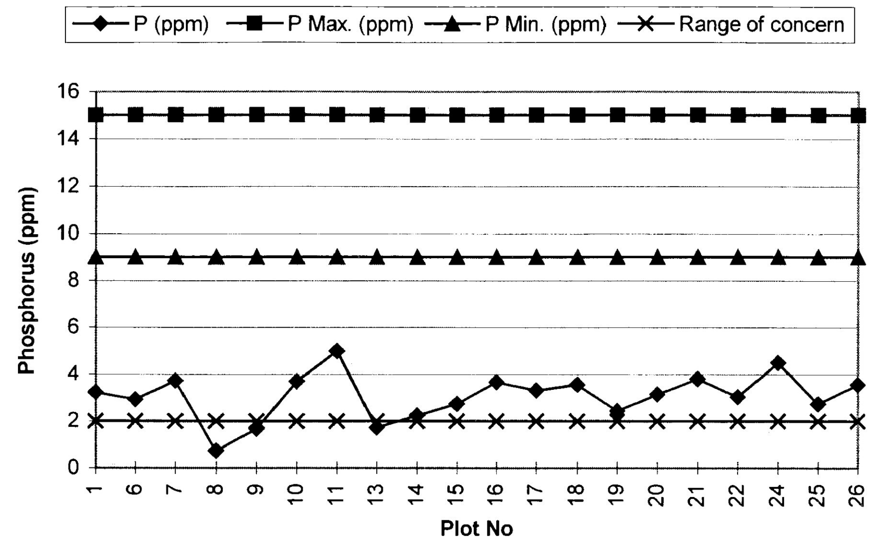


Figure 12: Current River phosphorous readings with normal range and value of concern.

Potassium deficiency is commonly associated with soils that are acid, have a sandy to loamy sand texture, low organic matter content, and low total cation exchange capacity and base saturation. Also the balance between K, Mg and Ca appears to be very important because calcium and magnesium both compete for the same carrier site and excesses of one may induce or aggravate deficiencies of another. In general soils that show < 15 ppm of exchangeable K during testing may be K deficient (Ballard 1986). Figure 13 is a graph of the Current River K readings plotted with the minimum and maximum range common for temperate soils. This graph indicates that the K levels in the samples were below the minimum range in all cases, but above the range of concern in most. Contrary to Ballard's rule-of-thumb, the samples with high organic matter were the ones displaying significant deficiencies in K. This information suggests that K deficiencies should not be critical to plant growth on site except in localised areas, although addition of this element via fertiliser should benefit overall plant growth on the site.

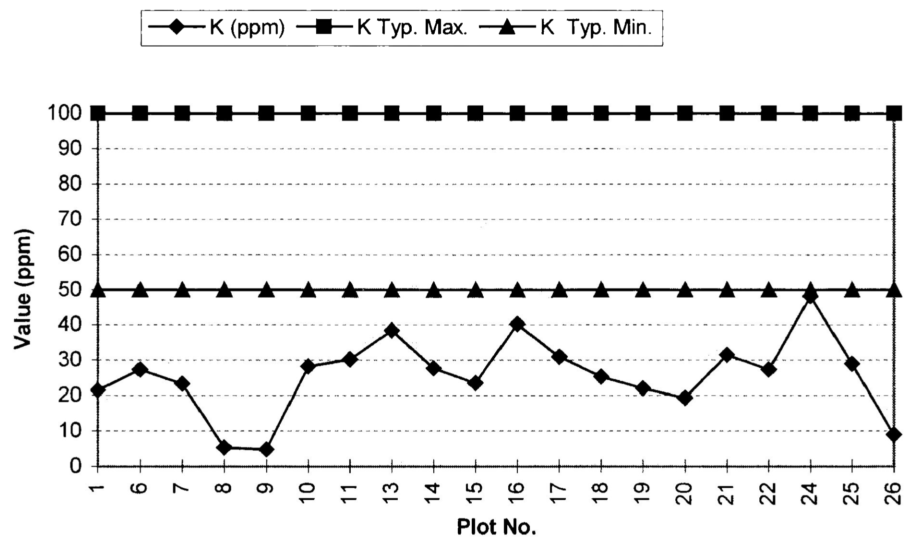


Figure 13: Current River potassium readings with the range for normal soils.

Copper deficiencies most commonly occur on coarse textured (sands and loamy sands) soils of igneous origin. These soils are often low in organic matter and have commonly been water-worked. Acid organic peats and mucks also appear to have low levels of total and/or available Cu (Ballard et al 1986). In addition soils that have experienced losses of organic matter and/or surface mineral horizons through burning, scalping, or erosion may also be deficient in Cu (Ballard et al 1986). Copper tends to be immobile and relatively uniformly distributed through soil profiles. It is easily precipitated, interacts readily with both organic and inorganic substances and has widely varying solubility due to pH. Copper tolerance varies among plant species and it is rare for plants to experience a deficiency of this element, as the requirement for most crops is quite low (Pais et al 1997). Deficiencies can occur and are "...most likely to occur on organic soils and on mineral soils with a high pH (>7.5) and or high (>2%) organic matter content" (Pais et al 1997). It should also be noted that high levels of available N can exacerbate Cu deficiency in soils with low Cu content (Ballard, 1986).

Currently there is no satisfactory method of assessing soil Cu status. There are two main reasons for this:

- Cu tends to be firmly complexed or chelated in soil organic matter, and interactions in soil organic matter, and
- Interactions between Cu and N, P and Mo make it difficult to estimate the Cu available for uptake by trees (Ballard 1986).

Be this as it may, four parts per million of Cu extracted by 1N HNO_3 or 0.2 ppm of Cu extracted by DTPA have been suggested as the critical Cu level for some agricultural crops. Critical levels for forest crops have not been established at this time, so agricultural levels were utilised. Figure 14 is a graph of Current River Cu readings plotted with Pais' (1997) normal range and common range thresholds. The graph indicates that the Cu readings for the site, while generally high, are still within the normal range. This suggested that neither Cu deficiency nor toxicity pose a problem.

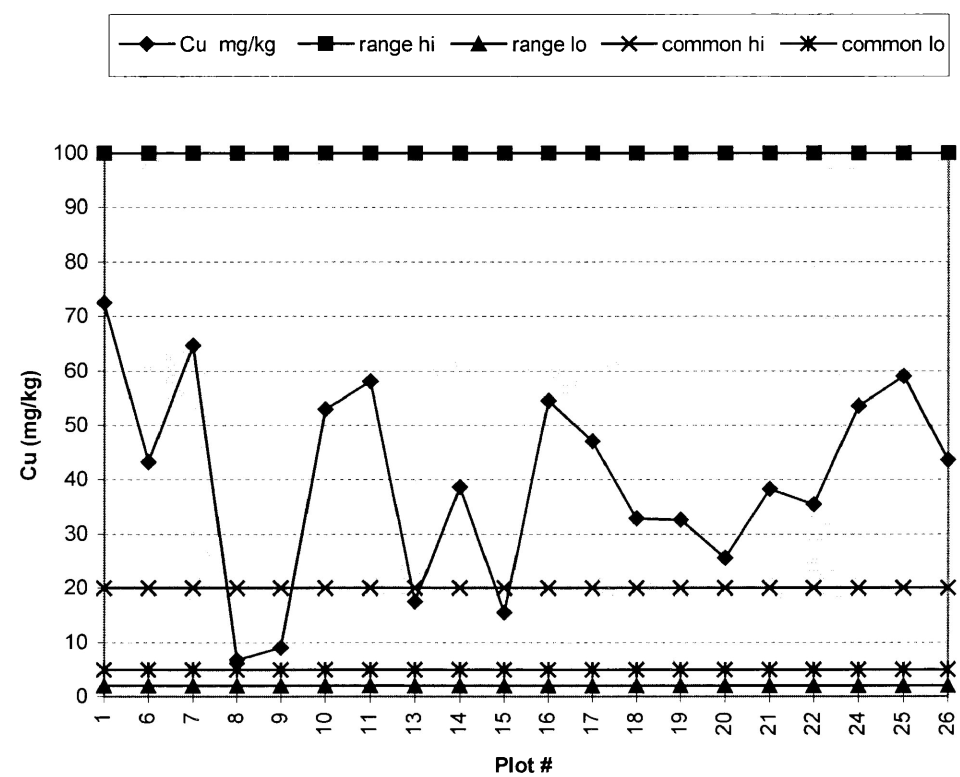


Figure 14: Current River copper readings with normal range.

Calcium is important not only in its role as a tree nutrient, but also for its role in soil improvement. It counteracts acidification and is important in determining soil structure. Critical levels of exchangeable or extractable calcium are not normally used as a measure of calcium deficiency because Ca deficiencies are rare in conifers. Instead, soil Ca or lime requirements are normally related to pH. Forest soils that have developed from acid igneous parent materials such as quartz- and granodiorites tend to be relatively acid and coarse-textured and are generally poorly supplied with Ca, Mg, and K. A soil with these characteristics and a soil pH of less than 2.8 is likely to be Ca deficient. Nevertheless, native confers appear to be able to extract an adequate amount of Ca, even when exchangeable Ca falls as low as 0.0001% (Ballard et al 1986). Michaud (1981) suggests that the typical range of Ca in a soil is 175 - 900 ppm. The Current River Ca readings have been plotted with this range in Figure 15. The graph indicates that for the most part the Current River soil's Ca content lies within or on the low boundary of the typical range. This, when considered with the generally high average pH levels for the site and in the context of Ballard's comments, suggest that Ca deficiency should not negatively impact plant growth.

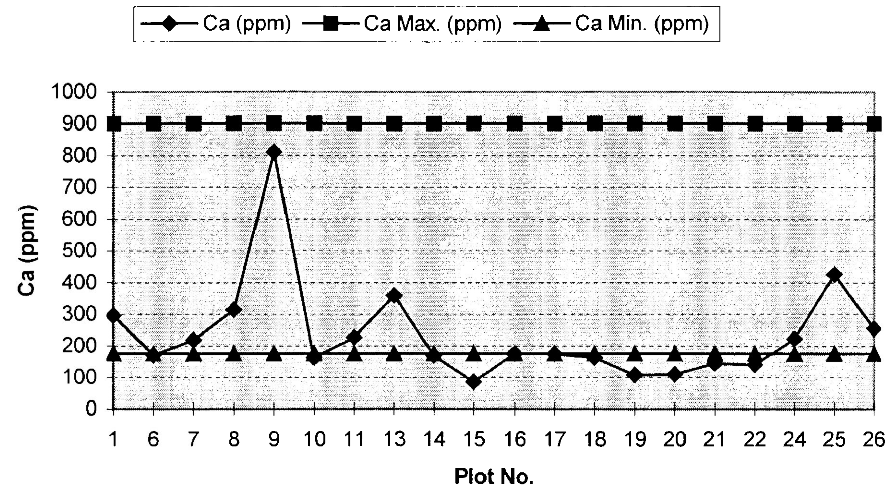


Figure 15: Graph of Current River calcium readings (ppm) with the range for normal soils.

Zinc deficiencies occur on the same soil types characteristic of copper deficiencies (Ballard et al 1986). "Soils with a pH of 6 or greater may have limited Zn availability; in addition high concentrations of available phosphates may also induce or aggravate possible Zn deficiencies" (Ballard et al 1986). Figure 16 graphs Current River Zn readings against the tolerable high and low ranges for soils, as well as the common high and low ranges for soils. The graph indicates that, while the site's Zn readings are generally well above the common range, the readings are within the tolerable range for the most part except in the instance of plot 11.

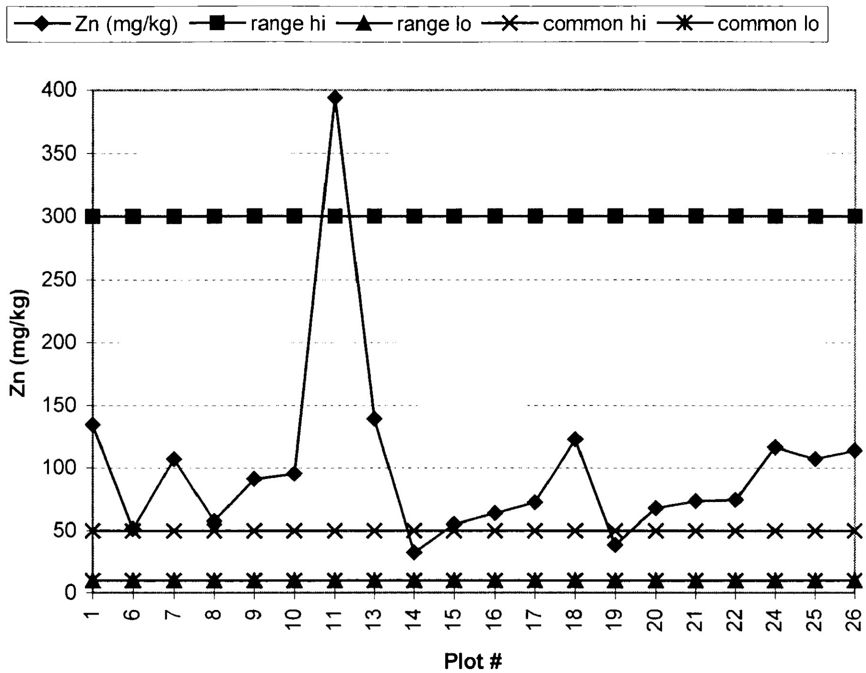


Figure 16: Current River zinc readings with common range and tolerable range.

Lead is a well-known toxic heavy metal and a major pollutant (Pais et al 1997). It is the least mobile heavy metal and tends to accumulate on the soil surface where, at higher concentrations, it may affect soil microflora. Soil lead availability decreases with increasing pH. It is not readily soluble in water and is found in relatively low concentrations. Extremely low levels (2 to 6 micrograms/kg) of lead may be necessary for plants, as there is some evidence of a stimulatory effect at low concentrations (Pais et al 1997). Figure 17 is a graph of the Current River readings plotted with the tolerable and common range for plants. The graph indicates that, for the most part, the lead content of the soils on the subject property was significantly above both ranges. Pais (1997) proposes 100 mg/kg of lead as the tolerable level for plants. This improves the situation somewhat, although, 8 of the subject plots still contain lead levels which are above his proposed tolerable level. The source of this lead is unknown, however, it has been speculated that it may have resulted from the unauthorised dumping of paint or other material on the site over the years. The immobility of Pb poses some problems for remediation. Solutions to high concentrations of heavy metals are described in the remediation options section.

The organic matter and clay content of a soil determines the distribution and behaviour of cobalt (Co) within it (Pais et al 1997). Cobalt deficiency in grazing animals is associated with alkaline and calcareous soils and soils high in organic matter. Generally the parent material determines soil Co content (Pais et al 1997). At present it is not clear if Co is essential for plant nutrition, although evidence indicates that it has a beneficial effect for some plants. Cobalt can easily be taken up through the roots and then translocated primarily in the transpiration stream (Pais et al 1997). Figure 18 is the Current River Co levels plotted with the tolerant and common ranges for soils. The majority of the readings are high and fall above the high common range but below the high tolerant range which suggests that Co content will not limit plant growth on the site. The low readings correspond to those plots with high organic matter readings.

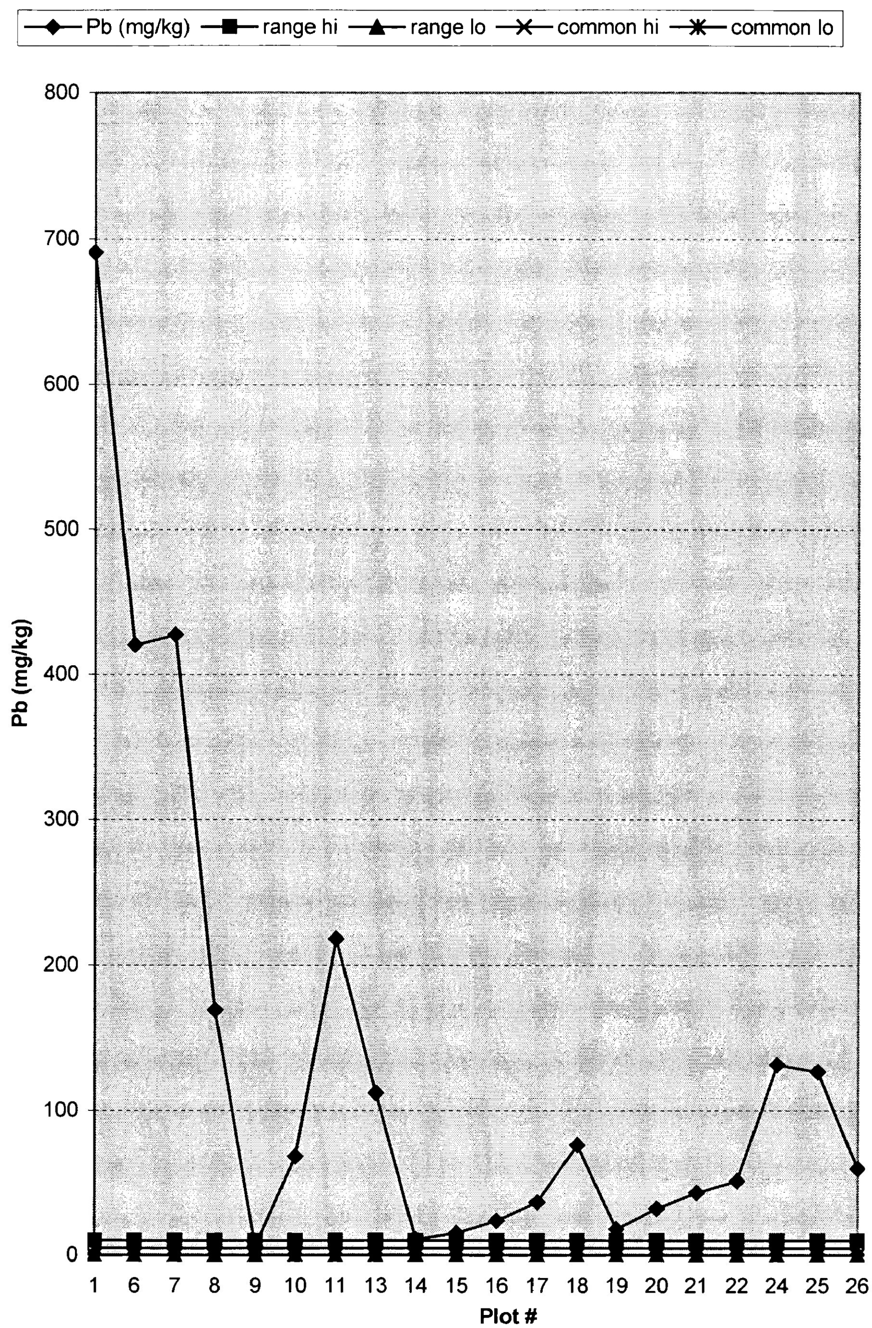


Figure 17: Current River lead readings with tolerable and common range (From Pais et al 1997).

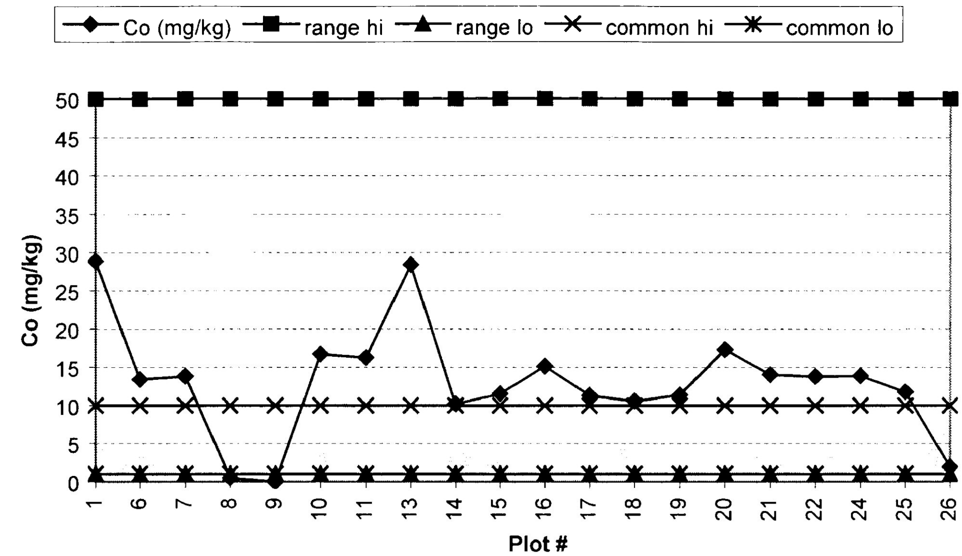


Figure 18: Current River cobalt readings with tolerable and common ranges.

Toxic levels of Cadmium (Cd) interfere with net photosynthesis and the uptake and transport of mineral elements in the plant. Toxicity is indicated by symptoms in plants of leaf chlorosis and necrosis followed by abscission. Plants exhibit variable sensitivity to cadmium concentrations in nutrient solutions ranging from 0.2 to 9 mg/kg. A 3 mg/kg concentration of Cd in plants will depress growth. Plant response to Cd varies according to species and concentration of other elements. Responses can be both synergistic and antagonistic. Cadmium solubility in soil decreases significantly with an increase in soil pH (Pais et al 1997)". Figure 19 indicates that the Cd levels on the Current River site are, for the most part, within the acceptable range. Two plots do have readings above the typical which may pose some problems.

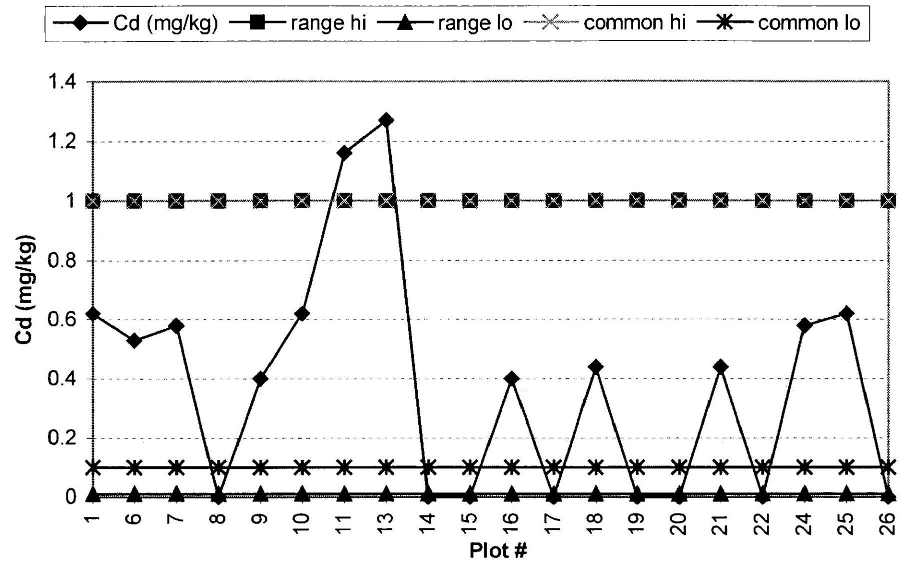


Figure 19: Current River cadmium readings with the tolerable and common ranges.

Chromium is found in nature in two forms; Cr^{+2} and Cr^{+3}. Of the two forms the Cr^{3+} cation is more stable and thus more commonly found in the environment. This form is also considered essential for some biological functions. The solubility of both forms is significantly affected by soil pH; the lowest solubility occurs between pH 5.5 and 8. Plants vary in their sensitivity to Cr; studies have found that 5 to 15 mg/kg of Cr in nutrient solution results in toxicity, and > 150 mg/kg of Cr in soil is toxic to some plants. Cr trends to accumulate in roots and is not easily translocated. There is some evidence of a stimulatory effect of low levels of Cr on plant growth (Pais et al 1997). Figure 20 is a graph of the Current River Cr values plotted with the tolerant range for plants and the common range. The sample levels fall predominantly within the common range and all samples fall within the tolerant range suggesting that the concentrations of this element on site will not pose a problem to plant establishment and growth.

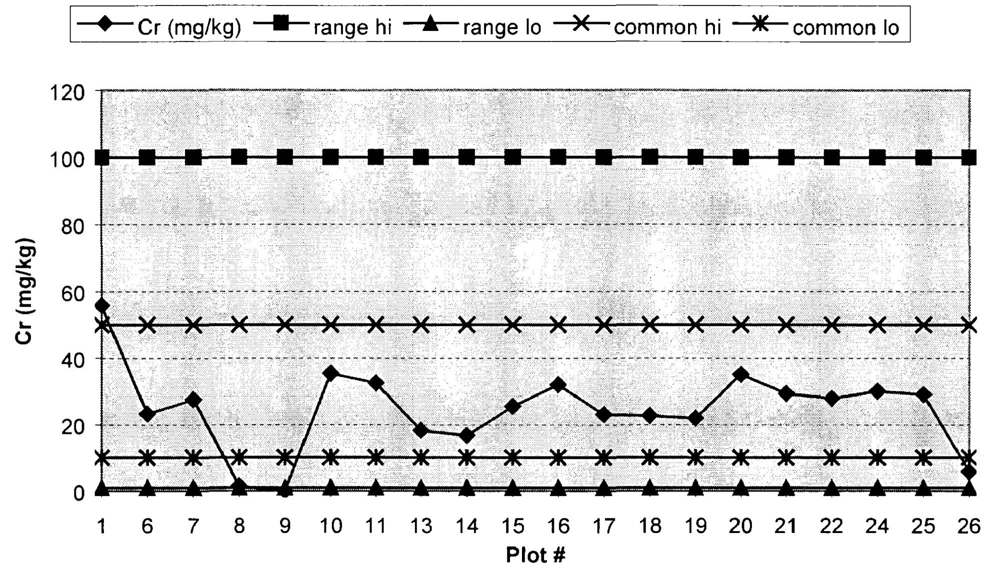


Figure 20: Graph of Current River Chromium readings (mg/kg) vs. the Normal Range.

From the previous discussion it is clear that the soil on the Current River site falls within the acceptable ranges for the most part. There are some specific instances where this is not the case. A number of plots were low in calcium, the potassium values for all plots were below the minimum range as were the phosphorous values. A number of plots possessed nitrogen readings that were far below "normal". These readings suggest that localised areas on the site are suffering from a macronutrients deficiency. The deficient areas do not uniformly correspond to the bark pile. The pH values for the site are all within the expected range for temperate soils and strongly clustered around the neutral. This may be due to the high organic content of the soil. The bulk density values for those areas where samples could be taken indicate that there is no significant soil compaction problem on the site save for localised areas that correspond to informal parking areas and roads. The most significant problem was the high level of lead found in many soil samples and the high levels of cadmium in two samples.

VEGETATION DATA ANALYSIS

The Vegetative data were obtained during the application of the site sampling plan described in Site Assessment Methodology For Urban Forest Restoration Planning and A Soil and Vegetation Sampling Plan For Land At the Mouth of the Current River (Sobering & Clarke, 1996). These data were obtained using a fixed plot technique and a floristic composition analysis was then used to analyse the findings. Data analysis options were reviewed in Analytical Methods For Soil and Vegetation: Urban Property On The Current River (Sobering 1997). After discarding the sampled tree strata data from this analysis, three phytosociological measures were calculated for the shrub and herb/moss stratums: relative dominance, relative frequency and importance value for each species.

Relative dominance of a species is a measure of coverage within the sample plot expressed as a percent (%) area. It is calculated by taking estimated % cover for each species per plot and then summing the mean % covers of all species by plot to obtain a plot total. These figures were then converted to a dominance figure by dividing the mean % cover for an individual species by the sum of the averages for the plot and multiplied by 100. The relative dominance values for a strata sum to 100 (Farmer 1995).

Species	Mean % cover	Frequency	Relative Dominance	Relative Frequency	Importance value
Solidago canadensis	4.05	25	4.04	8.06	12.10
Aster ciliolatus	0.05	5	0.05	1.61	1.66
Fragaria virginiana	0.9	20	0.9	6.45	7.35
Equisetum pratense	0.05	5	0.05	1.61	1.66
Callicladium haldanianum	0.25	5	0.25	1.61	1.86
Linaria vulgaris	0.3	10	0.3	3.23	3.52
Anaphalis margaritacea	4.3	15	4.29	4.84	9.13
Dicranum sp.	0.05	5	0.05	1.61	1.66
Trifolium pratense	0.75	5	0.75	1.61	2.36
Vicia americana	3.35	25	3.34	8.06	11.40
Taraxacum officinale	0.05	5	0.05	1.61	1.66
Achillea millifolium	0.8	15	0.8	4.84	5.64
Hydrocotyl americana	0.5	5	0.5	1.61	2.11
Sisyumbrium altissiumum	4.75	5	4.74	1.61	6.35
Sonchus arvensis	2.5	5	2.49	1.61	4.11
Typha latifolia	0.5	5	0.5	1.61	2.11
Cirsium muticum	0.25	5	0.25	1.61	1.86
Grass	60.25	70	60.07	22.58	82.65
Salix sp.	2.05	5	2.04	1.61	3.66
Corylus cornuta	0.5	5	0.5	1.61	2.11
Rubus ideas ssp.	5.75	25	5.73	8.06	13.8
Populus balsamifera	2	15	1.99	4.84	6.83
Melilotus alba	3	5	2.99	1.61	4.60
Picea glauca	0.05	5	0.05	1.61	1.66
Carryagana sp.	2	5	1.99	1.61	3.61
Rosa blanda	1.25	5	1.25	1.61	2.86
Plantago major	0.05	5	0.05	1.61	1.66
Total	100.3	310	100	100	200

Table 2: Table of importance values for Current river herbaceous data.

The relative frequency of a species is a description of the spread of a plant through the stand. It indicates how evenly a plant is distributed through a community and describes the percentage of sample points at which a species was found. This characteristic is calculated in a similar manner to the relative dominance. The estimated

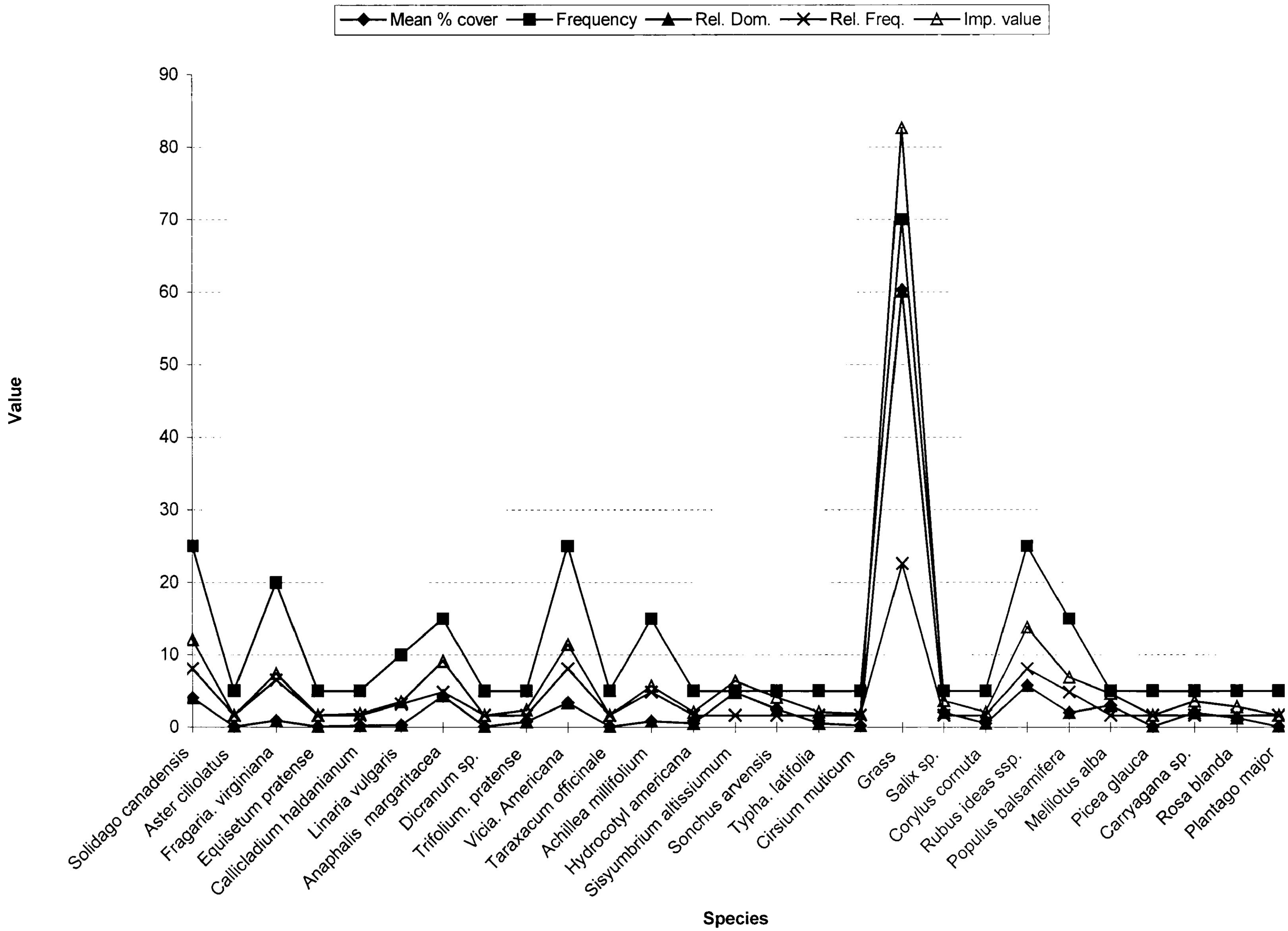
% cover is used in place of the frequency of species incidence. The sum of the relative frequency values for strata sum to 100 (Farmer 1995).

The importance value for a species is a measure of both its distribution through a stand as well as its coverage within the stand. It is calculated by summing the relative dominance and relative frequency values for each species. The importance values for each species within a stratum will sum to 200 (Farmer 1995).

Figure 20 is a graph of the mean percentage cover, frequency, relative dominance, relative frequency, and importance values for the species encountered during the sampling. According to this graph grass is by far the most important plant in the herbaceous strata. This striking dominance on the site is due to its high frequency within the site and high relative dominance within sample plots. Because the vegetative plot data were collected in the late autumn, a positive identification of the grass species found growing on site was difficult. However, in Northern Ontario a number of grass species are commonly found on disturbed sites such as the study area. Redtop grass (*Agrostis gigantea*), Fringed Brome Grass (*Bromus ciliatus* L.), Wire Grass (*Poa compressa* L.), Danthonia Grass (*Danthonia spicata* (L.) Beauv.), and False Melic Grass (*Schizachne purpurascens* (Torr.) Swallen) are all species common to this region which are found on dry waste sites such as this. While the herbaceous stratum was dominated by grass, a number of other herbaceous species occurred on site somewhat more frequently than the bulk of the sampled species. This second tier of plants is composed of Canada goldenrod (*Solidago canadensis* L.), American vetch

(*Vicia americana* Muhl.), wild red raspberry (*Rubus ideas* L. *ssp. melanolasius* Focke), pearly everlasting (*Anaphalis marga*ritacea (L.) C.B. Clarke), and common strawberry (*Fragaria virginiana* Dcne.). All of these species are found predominantly in open, dry, disturbed areas similar to the study site.

Figure 21: Graph of Phytosociological Values.

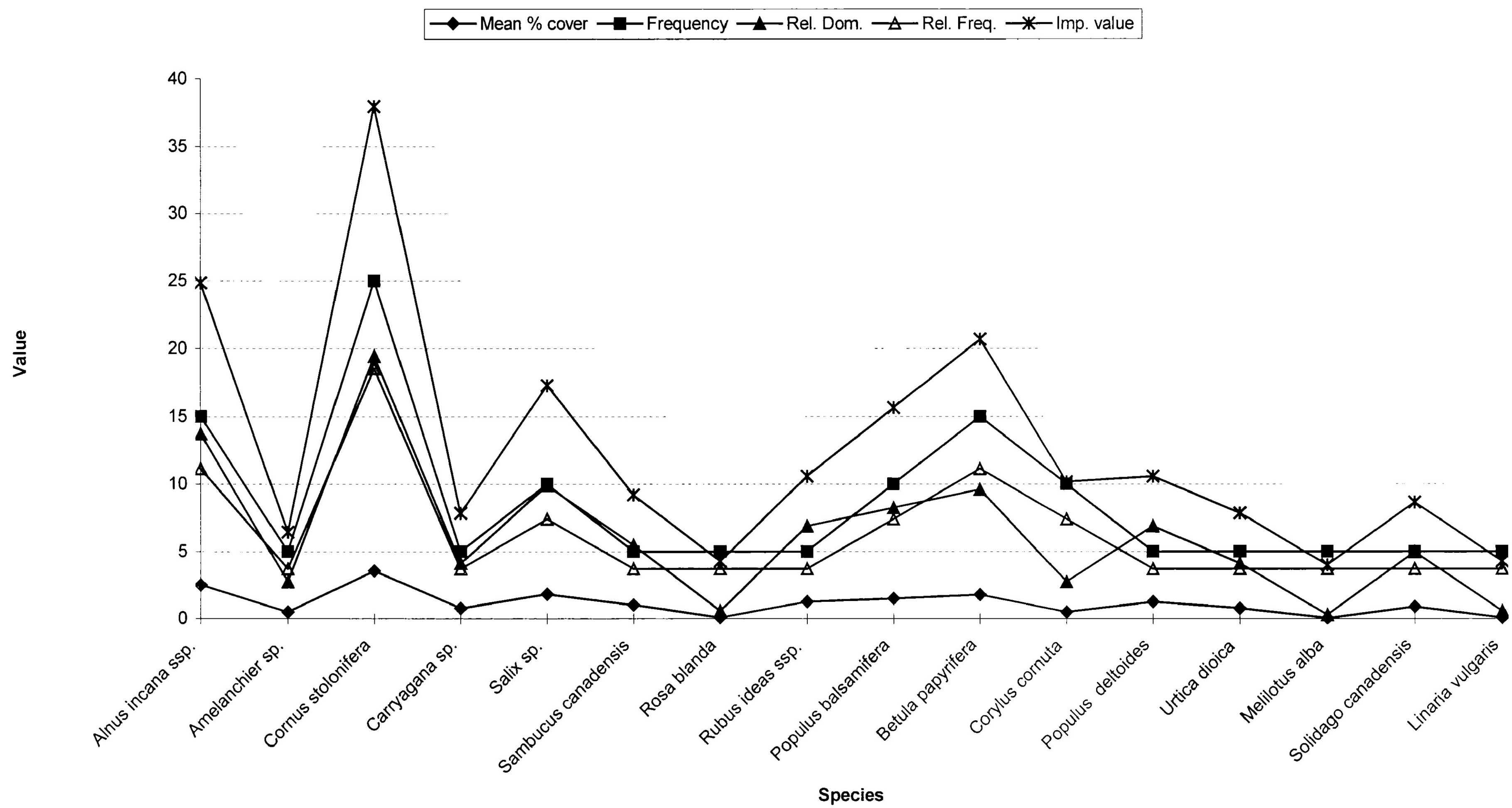


The relationship between species in the shrub strata is different from that described in Figure 21 for the herbaceous species. Figure 22 is a plot of the Mean % cover, frequency, relative dominance, relative frequency and importance values for the species encountered in the shrub strata during vegetative sampling. Red osier dogwood (*Cornus stolonifera* Michx.), with an importance rating of almost 38, was the species with the highest importance value in the shrub strata. This rating reflects a strong balance between this species frequency and relative dominance within the site. The beaked hazel (*Corylus cornuta* Marsh.) is a common species that is found in a wide variety of moisture regimes and landscape features. Frequently it is located on disturbed lands (Legacy et al 1995). Speckled alder (Alnus incana ssp. Rugosa), willow (*Salix sp.),* balsam poplar (*Populus balsamifera* L.), and paper birch compose the second tier species. To this point the plants with the higher importance values have consistently been suited to well drained, dry, open, disturbed sites. These second tier plants, however, do not follow this trend. The relatively high importance value for the two hardwood species shows that natural regeneration of tree species is occurring on site at a moderate level. The presence of paper birch is not unexpected in this situation as this species is shade intolerant, abundant and commonly found in dry upland areas. Balsam poplar is another species of tree found on the study site. Unlike the paper birch this species prefers moist to fresh, clay to medium-loamy soils in pure or mixed stands which is somewhat inconsistent with the site conditions (Legacy et al 1995). Speckled alder is also present on the site. This species is commonly found in sites that range from wet organic locations to moist clay to medium-loamy uplands (Legacy et al 1995). However, it is also found in significant amounts on this generally sandy and well-drained site. In light of the finding that most of the other species with high importance values prefer dry, well drained, disturbed sites, the presence of this species is likely associated with pockets of seepage within the site and with the riparian areas along the relatively natural portions of river bank. The strong presence of willows on the site provides very little information as these species hybridise very easily and consequently can be found over a wide variety of forest habitats and site conditions (Legacy et al 1995).

Species	**Mean % cover**	**Frequency**	**Relative Dominance**	**Relative Frequency**	**Importance value**
Alnus incana ssp.	2.5	15	13.7	11.11	24.81
Amelanchier sp.	0.5	5	2.74	3.70	6.44
Cornus stolonifera	3.55	25	19.45	18.52	37.97
Carryagana sp.	0.75	5	4.11	3.70	7.81
Salix sp.	1.8	10	9.86	7.41	17.27
Sambucus canadensis	1	5	5.48	3.70	9.18
Rosa blanda	0.1	5	0.55	3.70	4.25
Rubus ideas ssp.	1.25	5	6.85	3.70	10.55
Populus balsamifera	1.5	10	8.22	7.41	15.63
Betula papyrifera	1.75	15	9.59	11.11	20.70
Corylus cornuta	0.5	10	2.74	7.41	10.15
Populus deltoides	1.25	5	6.85	3.70	10.55
Urtica dioica	0.75	5	4.11	3.70	7.81
Melilotus alba	0.05	5	0.27	3.70	3.98
Solidago canadensis	0.9	5	4.93	3.70	8.64
Linaria vulgaris	0.1	5	0.55	3.70	4.25
Total	18.25	135	100	100	200

Table 3: Table of importance values for Current river shrub data.

Figure 22: Graph of Shrub Layer Phytosociological Values.



The vegetative data collected from the site do not paint a picture of a uniform community in species composition or process. The vegetation present today reflects a process marked by planned ornamental plantings and chance colonisation by native species and escaped exotics. Despite the differences in species composition across the site this information does, however, support our understanding that the subject property was heavily disturbed and subsequently colonised by early successional species and dry nutrient poor soil loving species. This resulted in a site dominated by grassy meadow with an outer fringe of multi-staged woodland with some areas in decline and others ascendant.

DISCUSSION

SITE PLANNING

The key to successfully planning public open spaces is to involve the community in a meaningful manner in programming and site planning at the early stages of the project. It is fortunate that the citizens of the City of Thunder Bay have recently expressed their long term vision for the waterfront in the report entitled <u>The Next Wave: Charting a Course for Thunder Bay's Waterfront.</u>

The people of Thunder Bay expressed a broad general vision for the waterfront with some specific detailed concepts for the sections of the waterfront corresponding to major community centres. Unfortunately, the Current River site is not located within these parts of the waterfront that received the more detailed treatment. While the report does not contain direct, clear instructions about the programming of the project site there is sufficient direction within the report to allow logical conclusions to be made on what activities should be provided for on the site.

One of the clearest statements in the vision document is the requirement for continuous physical public access along the waterfront. In addition to a waterfront link there is another logical way to link the site to the City: through the Current River greenway. Since Waterfront Drive is not continuous at this time, the waterfront connection must be considered a long-term goal. The greenway connection, however, can be achieved in the short term because there are fewer financial and physical barriers to surmount. The most obvious choice would be to link the path system developed on the subject property with the existing trails existing in the Current River park network.

The report also supports the enhancement of habitat on the shoreline and inland portions of the project site. There is not a specific recommendation as to what type of habitat is preferred for the site; however, it does suggest the enhancement and diversification of riparian vegetation communities and the re-establishment of marsh habitat along the shoreline where possible. This guidance suggests that where appropriate aquatic habitats should be established on the site.

One of the main principles of the master plan is that access should be provided at the water's edge. This site provides an ideal opportunity to achieve this goal.

Waterfront access could be enhanced on this site by the development of a system of trails that lead to the water's edge. In places these trails could be cantilevered from the concrete wall along the north river bank to provide unlimited access to the river for recreational fishing opportunities, views to neighbouring industrial activities, and to provide a stronger connection to the harbour. The trail system on the site must connect the three physically separate and distinct parts of the site. This will require a bridge at some location along the Current River. Harris (1996) suggests that when designing a property for walking, extensive areas of attractive land are required as well as small local areas for strolling/exercising dogs and woodland or scrub to provide seclusion and variety.

The report also states that it is important to enhance views to the waterfront and to recognise and highlight the cultural importance of the waterfront to the Community. Again the project area provides an ideal opportunity to do this. The site is ideally located to allow the public to view the loading of grain ships from a safe distance, the activities of the PASCOL shipyard and the work of local fishers at the public wharves. The site also possesses a number of cultural artefacts that connect the land in its present state back to its industrial past. As mentioned previously, the historical records indicate that this area was the location of the community's first pier and the site reconnaissance found evidence of pier pilings in the harbour just off of the study site (a remnant of the mill operations). The reconstruction of this pier could meet a number of the community's historic and unlimited access goals if designed properly. It would create a link to the past industrial use of the area for forestry and the early transportation infrastructure of early Port Arthur, enhance views to the waterfront, and enhance viewing opportunities of the working harbour. The site also has its own important industrial history and artefacts associated with the fish hatchery, powerhouse and pulp mill. Another way to make connections to the historical past of the property is to use relic materials in infrastructure features such as paving, buildings, signage, fountains, etc. A permanent historic interpretative display could also be developed on the site using historic photographs from City's archives and the quotes from the correspondence of historic personages. A selection of activities or events that could be profiled are the PASCOL shipyard and its role in the wars, the United Grain Growers terminal, the pulp mill, the power house and dam, the fish hatchery and fishing, and the railway. Harris (1996) advises that to encourage contemplative areas and viewpoints the designer must make use of high land and variable topography. Providing benches and other places to sit is another key provision for these areas. These could be located on promontories on the site, on towers, boardwalks or piers.

There are a number of other possible uses of the site that are not suggested by the vision report. One use that has been suggested is developing a portion of the site as a camping area for groups such as scouts. To facilitate this activity the site would need to have services (eg. water, drainage, waste disposal), open space for ball games and dogs, possess a flat grassed areas where tents could be pitched, and tall dense vegetation to give shelter and screening (Harris et al, 1996). Of course picnicking is naturally associated with camping and relaxing out of doors. To facilitate this activity picnic tables and BBQ pits for families and groups will have to be provided on the site. The designer should also consider the possibility of providing small open areas, and creating landforms and/or plantings of vegetation for shelter (Harris et al, 1996).

The site has also been identified as the location of a long-standing urban fishery (Iwachewski 1995). The walleye population at the mouth of the Current River is considered to be degraded hence the reason for the habitat restoration work conducted by the OMNR. For this reason the Ministry would not look favourably to the creation of additional fishing pressure in the area (Iwachewski, 2000). This poses a considerable design challenge as the City's vision of enhanced public access to the waterfront could conflict significantly with the conservation goals of the OMNR in this location. This conflict could be addressed through the trail design, unfortunately, informal trails are likely when formal trail networks do not meet public expectations. The redevelopment of the site will create the expectation of river access within the fishing community and if not provided formally may result in continued bank instability and erosion. This is particularly a problem on the south bank of the river as the concrete retaining wall on the north bank of the river protects it from the erosion that can be caused by heavy foot traffic. While the restoration of the north bank to a more natural condition would be a significant benefit from a habitat perspective, there are some significant downsides to that concept. The high financial cost of remediating the channelisation would, of course, be a significant consideration, as would the potential short-term negative impacts to fish habitat of the removal effort. The retaining wall is part of the historic past of the site and could be creatively used to create safe fishing platforms along the river. These would have the added advantage of reducing potential bank erosion in unstable areas due to high traffic. Should the decision be made to enhance fishing facilities on the site consideration should be given to creating a place to clean catch and safely dispose of fish waste. In addition to fishing there is the opportunity to provide interpretative information about local fish species in a manner similar to that described for the historical context and there is also the potential to recreate a community fish hatchery as an educational tool for local school children.

While many will visit the mouth of the Current River by bike, ski and foot, there will be a substantial number of people travelling there by automobile. In order to accommodate the automobile public parking must be provided for those who chose to drive. There are a number of ways to provide parking to the site; however, it was identified during the early research phase of the site that the City owns the derelict parking facilities adjacent to the site. This land is designated for parking in Figure 22. Since these lands are already debilitated from past use the logical course of action is to renovate an appropriate portion of existing parking facilities for use as part of the site infrastructure. One of the main benefits of recycling these existing parking facilities is that it maximises the portion of the site for restoration.

DESIGN

It is at the design stage of a project where the vision expressed by the community plan and program become translated into a concrete functional concept. For a project of this type (i.e., where public use and landscape restoration are jointly being undertaken) success depends upon creating a balance between the human needs for the site (the program) and its natural elements or habitat. In the following section an attempt to balance these two potentially conflicting aspects to meet both the needs of the city resident and the natural ecology of the site.

Program

As described above, a site program is a description of the desirable human uses of a piece of land. It can also be described as the activity design of a landscape. For example a broad program for a park space could be an athletic park. The specific elements which make up that park could be two soccer pitches, four baseball diamonds with their associated backstops, bleachers, dugouts, concession stand, lighting, parking, restrooms, parking etc. In the case of the land in question the broad program will be based on the City's vision. A nature park with an interpretative element is recommended. Figure 22 is a sketch of a proposed program/design for the Current River site. This proposal is included as a suggestion of one possible site treatment in order to generate discussion between citizens, leaders and civic staff as the community works out the details of what works for it.

One of the key elements in the design is the provision of public connections to the waterfront. This will be in the form of trails, bridges, boardwalks and a wharf/pier. The pier is proposed for five reasons: 1) it can be used to make reference to the historical fact that this was the area in which the first wharf in Port Arthur was located;

2) the pulp mill was serviced by a pier/wharf and the existing piling still exist; 3) the reconstruction of a wharf/pier will allow the public a superb viewing platform to watch the working waterfront in action which meets the enhanced views to the waterfront principle; 4) it will provide new fishing access opportunities to the harbour; and 5) it will provide temporary moorage for visiting the site by boat. For the site to work as one unit, a pedestrian bridge must join both banks of the river. There are a number of possible locations for the bridge. One is to link the north and south banks by two short spans connected to the main island in the mouth of the river. This would mirror the previous access road layout from the period when the site contained the mill. Alternatively, by keeping the islands physically isolated from human activity they could be protected for purely habitat purposes and act as a visual focus to the site. If this is the preferred option a longer span bridge could be constructed across the river further upstream. This bridge could follow the course of the pipeline that transported pulp from the mill to the paper plant forming a direct reference to the historical past of the site.

During the site reconnaissance it was noted that the Current River site formed a natural terminus to the greenway lining most of this watercourse. It is strongly recommended that this site be connected to this network of parks and protected areas (this will meet the linkages with natural corridors design principle). It is suggested that the location of the pipeline that serviced the powerhouse be considered the natural location of this link as the culverts under the rail line constructed to accommodate this pipe could provide a safe seasonal pedestrian underpass. In addition it is noted that proposals have been made to upgrade Waterfront drive and create a bicycle/pedestrian link. This site is a natural recreational destination or waypoint and the site design should consider providing for the linking of the site into the broader greenway system.

One of the planning and design principles from the waterfront master plan is to recognise and highlight the cultural importance of the waterfront. A number of historic activities have been identified on the site. The powerhouse, fish hatchery, pulp mill, boat yard, and wharf are all part of the site's history and the cultural heritage of the City. The celebration of this working past could take place in a number of ways. One technique that has been used at Canada Place in Vancouver is to mount historical photographs on signs along with a description of the significance of the scene represented in the photograph and to face the sign along the direction the historic photo was taken thereby providing a contrast between the past and the present. Because of the varied history of the site archival photographs of shipyards, the grain handling industry, fishing fleet, recreational use, conservation (fish hatchery), power generation, wood milling, and boat yard activities can all be highlighted to explain the past use of the land. In addition quotes from citizens involved in these activities could be used on the signs (taken from books, letters or interviews) so that the story of the waterfront could be told in the words of the people who developed the area. There are a number of reasons supporting the reconstruction of the pulp mill wharf on the remnants of its piling. Firstly the wharf could be used as a direct reference to the fact that the first wharf on Thunder Bay was located in this area. It is also a direct physical link to the era when the mill operated onsite. Finally, it will improve access to the water for fishing and viewing the activities of the working harbour.

The site reconnaissance located a number of artefacts on the site from past human activities. These consisted of concrete walls, building foundations, brackets for the pipe that fed the powerhouse from Boulevard Lake. These artefacts could be used in paving patterns, fountains, benches, or other physical elements of the landscape to provide a connection back to the history of the site. Utilising an industrial theme in site furniture design and material could further strengthen this theme.

As noted previously, it is reported that the land at the mouth of the Current River was a popular and productive fishing site and that it continues to be a place to fish. It is recommended that the design consider providing safe access to the river for fishing as well as a place to clean the catch and dispose of entrails. As part of the site design a series of paths and platforms, designed so they won't damage sensitive ecosystems, should be considered for installation along both banks of the river. In addition, interpretative signage describing the species present and their lifecycles should be provided along with the fishing infrastructure.

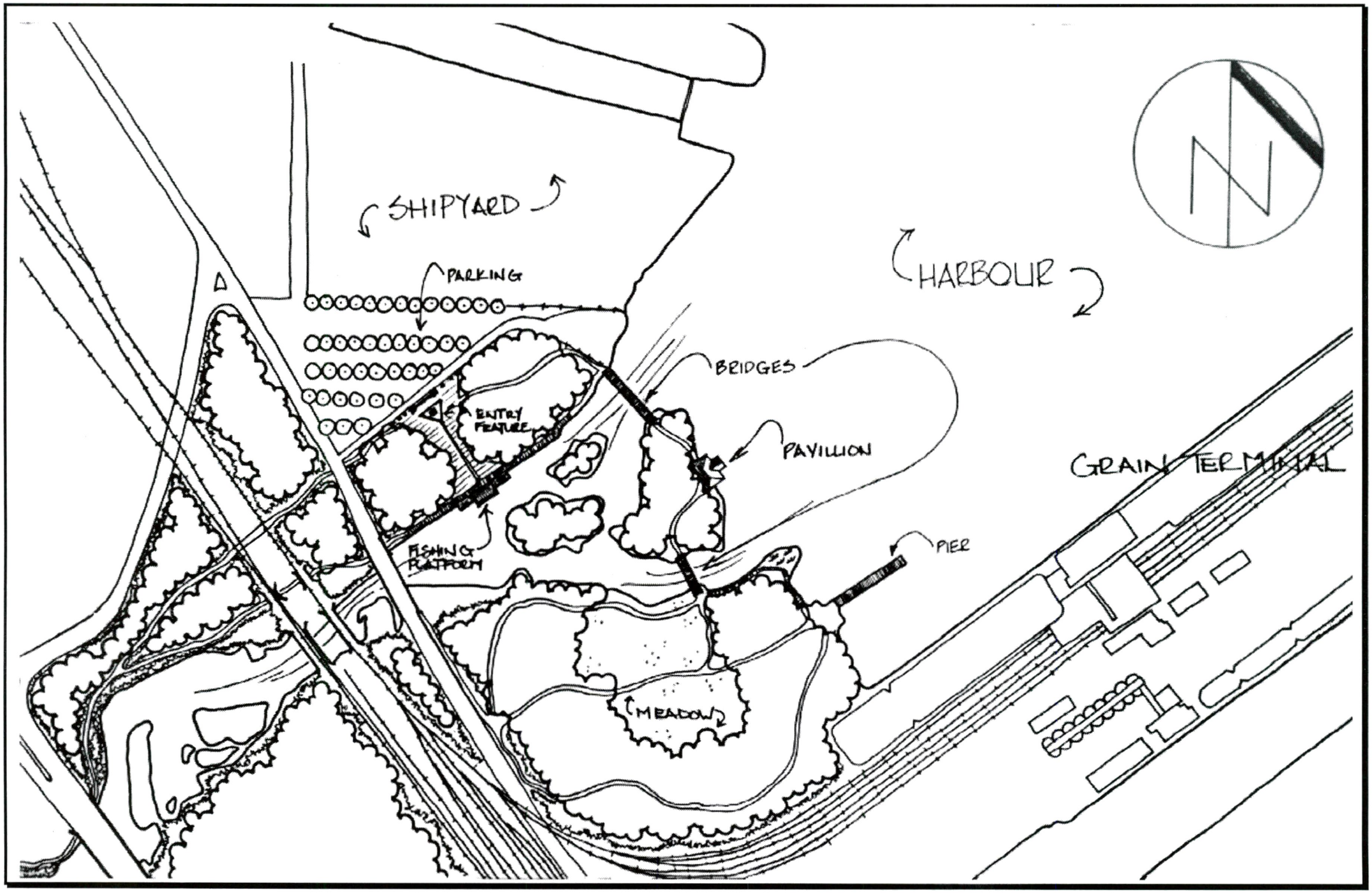


Figure 23: Proposed Conceptual Design For Current River Site.

Habitat

After determining how to address human needs on site, the next step in this process is to determine what kind of “habitat” will be created there. In essence habitat creation is another form of landscape design. While describing the process of habitat creation as design may be unusual, it is accurate. There are a number of “design’ options available to the city in rehabilitating the subject property depending upon its goals for the site. There are two general categories of landscapes: woodland (shady) and meadow (sunny). Shady landscapes are modelled after forest and woodland communities, while sunny landscapes are based on prairie and meadow landscapes (Harker et al 1993). In addition to these two main community types the designer may chose to use a wetland community as a model for the designed landscape or select some combination of the three to create diversity.

Trees and shrubs dominate Forest landscapes. These communities are complex environments with a great diversity of colour, form, texture, odour, and sound. They provide shelter from the elements as well as a sense of solitude and privacy, qualities that act as a strong incentive to select the forest community as a restoration model (Harker et al 1993).

Prairie communities serve as the models for those sunny herbaceous landscapes dominated by grasses and forbs we know as meadows. Prairie landscapes vary in character depending upon location. In the Great Plains and Midwestern regions, where it formerly occupied vast areas, the prairie composed expansive vistas of tall grasses and brightly coloured flowers. In the predominantly forested eastern regions, however, these communities often occurred as openings of various sizes in the forest. In this context they are sometimes better known as meadows or glades (Harker et al 1993).

A prairie community achieves its most dramatic appeal when recreated or restored on a scale that emulates the expansive quality so characteristic of the prairie regions; however, a well-designed wildflower meadow, even on a smaller scale, possesses all the elements that make the prairie such a desirable landscape system: open viewscapes; a seasonally changing diversity of colours, shapes and textures; low maintenance requirements; and high value for wildlife (Harker et al 1993).

A third type of landscape that can serve as a restoration model is the wetland. Wetland (palustrine) communities serve as models for landscapes characterised by emergent aquatic plants. Most wetland plants are sun loving. Wetlands can be created from scratch or existing ponds and lakes can be enhanced by planting emergent aquatic plants along the shores. When creating this type of landscape, abrupt or steep shorelines may need to be graded to reduce the slope before plants are installed. In addition to creating ideal conditions for many plant species developing gradual or graduated shorelines also enhances water access for wildlife (Harker et al 1993).

Finally the designer may chose to use a combination of the above landscape types in their habitat design. This may be done to reflect differences in site conditions, to maximise specific habitat conditions for wildlife (eg. edge conditions), or to accommodate different human uses. The current pattern of habitat development on the Current River property, considered in combination with the proposed program elements, suggest that this is the best approach for the study site. It is proposed that all three landscape models be used in this restoration. See Figure 23 for the proposed placement of the main habitat models on the site.

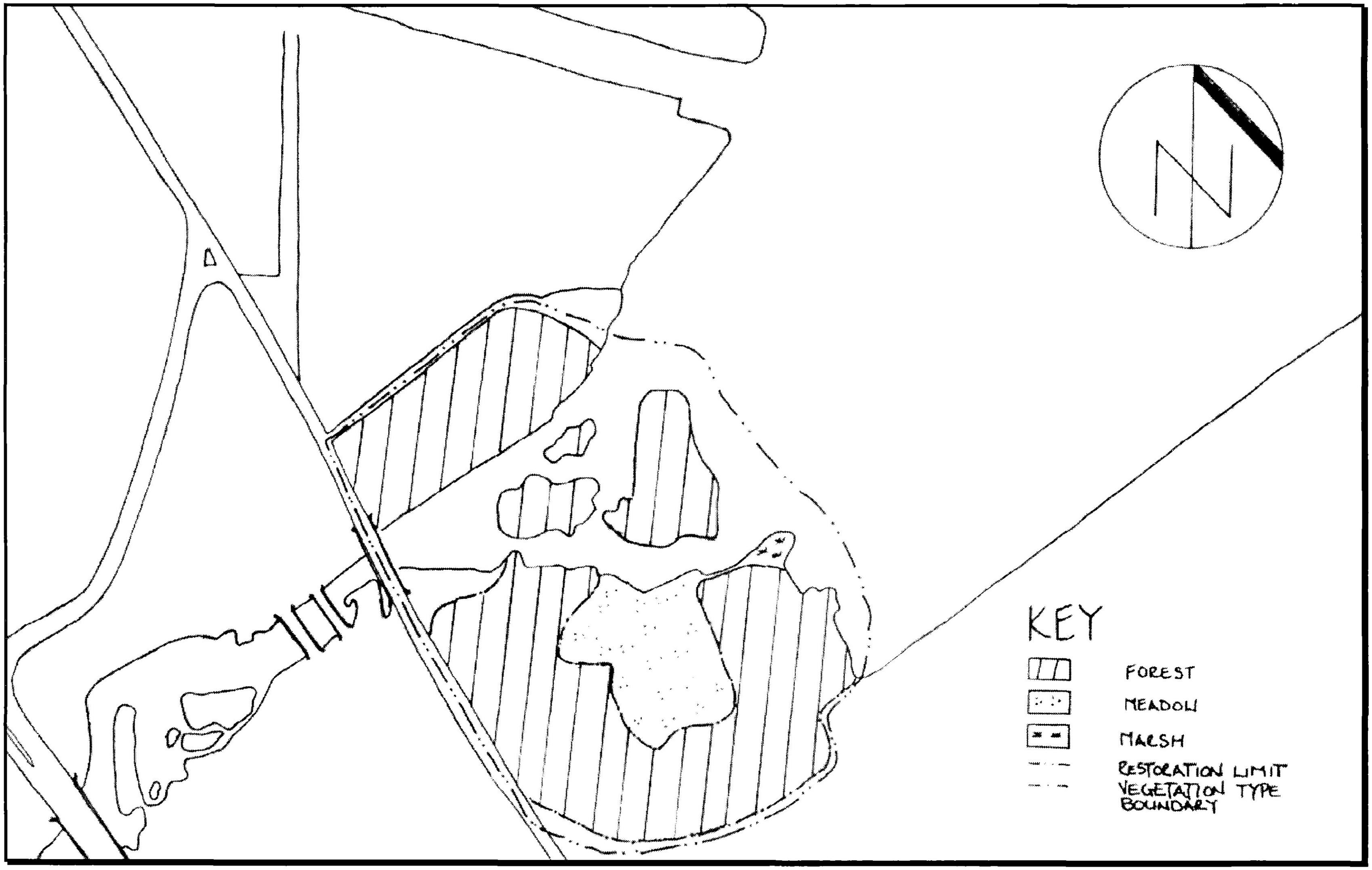


Figure 24: Proposed Habitat Distribution.

REHABILITATION METHODS

The final decision that the restorer must make is what method or type of restoration process should be applied to the site. The following section describes a number of approaches to restoring land and the techniques commonly used with each approach. There are four basic approaches; the horticultural model, naturalisation, ecological restoration and managed succession. While there is a significant amount of overlap in the actual techniques used in these four approaches - they represent more of a continuum rather than definite classes - there is a difference in the manner that the techniques are utilised between approaches. This section has been organised in this fashion to provide the City with a detailed range of options to assist in their restoration planning process. Each approach will be discussed in further detail in the following paragraphs.

Horticultural Model

Horticulture is defined as "...the science and art of growing fruits, vegetables, flowers or ornamental plants" (Websters 1983). This standard dictionary definition of horticulture "...embodies the ideal of nature under control. Each tree, shrub and flower is a symbol of human ingenuity; an artefact in a humanised landscape"(Hough 1989). While these ornamental landscapes of turf grass and plantings of introduced species are the common expression of nature in the city, they do not provide the same ecological benefits to the city as a more natural expression of nature. An examination of the typical planting specifications for a landscape design will show why. These specifications set out the technical requirements for plants that will ensure that the plant is symmetrical, well shaped and grown free from competition. Planting requirements ensure an ideal growing medium for plant roots, irrespective of existing soil conditions. Topsoil and a variety of soil amendments are required to ensure optimum growth conditions for turf and groundcovers. Irrigation systems are often needed to ensure regular and systematic watering. Together with pruning, mulching, spraying and other established horticultural practices, the effect of technology is to create environmental conditions that are as insulated from the nature of the place as possible (Hough 1989). The down side of creating a landscape based on this model is that it provides little ecological benefit and requires a high level of expensive maintenance. While the horticultural model has a number of negatives its one strong point is that it corresponds to the North American ideal of nature in the city. Consequently, it is culturally acceptable. Because horticulturally based landscapes are the norm in cities it was deemed unnecessary to describe the techniques in as much detail as the other approaches.

If the community selects this model, a general model of action would likely be the following: Clear the site of scrub vegetation. Protect those ornamental and native trees that merit retention by placing snow fencing around the drip line of the tree or mass of trees. Either apply herbicidal sprays or repeated cultivation of the soil to kill weed seeds. Strip organic material from deposit on site and set aside for mulching. Grade the site and then place topsoil on top of the cultivated parent material (18 inches approximately). Take appropriate steps around root systems of retention trees. Then plant by hand. Mulch, fertilise and irrigate to ensure establishment of plants. The site will be maintained by regular application of fertiliser and weed control.

Naturalisation

Naturalisation or natural landscaping is the "...art of capturing the character and spirit of nature in a designed landscape" (Harker et al 1993). It is commonly used to restore the natural beauty of the landscape by creating designed landscapes utilising native plants in a community context. While the long-term goal of natural landscaping is to create self-sustaining landscapes, it is not trying to recreate the complexities and balance of ecological systems (Harker et al 1993).

A principle foundation of natural landscaping is the use of native or indigenous species of plants. A native species is one that occurs in a particular region as a result of natural forces and without known or suspected influence (Harker et al 1993). The advantage of utilising native plants is that because they are part of the natural history of a region, they form naturally diverse communities and are well adapted to the climate, soils and other biotic and abiotic characteristics of their region of origin (Harker et al 1993). By virtue of these characteristics native plants provide a pleasing aesthetic, conserve natural resources, reduce maintenance costs, preserve biological diversity, and prevent species extinction. While the biological and environmental reasons for using native plants are significant, the economic advantages are great also. The economic advantages flow from the fact that "Native plants are adapted to the climatic and environmental conditions of their indigenous regions" (Harker et al 1993). When natives are placed in appropriate growing conditions they will require only minimal use of irrigation, mechanical control (i.e., mowing), fertiliser and pesticide to thrive which reduces cumulative environmental impacts and maintenance costs. This reduction in mowing and fertilising can result in savings of 25-30 percent when compared to turf (Stroud 1989 as cited by Harker et al 1993).

There are two main ways to design a naturalised landscape. The first is to select a desirable ecological community as a model and then attempt to create site conditions that are favourable to developing that community. While this method can produce the desired result, there is no guarantee of success and it requires substantial investment in effort and finances. The second, and more effective approach, is to analyse the site, determine its characteristics and select one or more natural communities adapted to these conditions as landscaping models (Harker et al 1993).

There are a number of general design and planning concepts that should be followed to maintain the maximum efficiency of a project. The first is to source plant material from a site as close to the planting site as possible (Harker et al 1993). This assures that the plants selected will be hardy and adaptable to local growing conditions.

The second principle is to work with the site not against it. For example the condition of the soils at various locations within a planning site may affect the potential for establishing different types of natural communities. While modern soil improvement techniques make is possible to grow plants on naturally poor or highly degraded sites, the costs of replenishing soil structure, moisture retention capability, fertility and other qualities should be considered (Green and Marshall as cited by Harker et al 1993). Rather than working against the naturally existing soil characteristics to create site conditions to support a previously selected ecosystem, the designer should view the site characteristics as opportunities not impediments to the project. For instance soils with naturally poor drainage will often support a wetland or bog community, while dry, excessively drained sites may support xeric forest, glade or dry prairie or desert communities (Harker et al 1993). By working with the site there is less need for expensive inputs into the soil and long term maintenance making this approach significantly more cost effective.

A third design consideration is the retention of existing vegetation. Retaining existing vegetation is desirable because it can reduce the overall costs of implementing the plan, particularly in the case of tree installation, as they are a long-term investment in the landscape. For this reason, healthy trees should always be retained where possible regardless of their desirability. Even undesirable trees can often be retained to provide needed shelter for new plantings until they are well established (Harker et al 1993).

Finally the restorer should recognise that the more disturbed or degraded a community, the more aggressive a program of weed eradication and planting will likely be required (Harker et al 1993).

Design

“The presence of existing natural communities, as well as the prevailing natural character of the surrounding landscape will, in large part, influence the design. Knowledge of how the pre-developed landscape appeared is helpful in developed areas” (Harker et al 1993). As mentioned previously, naturalised landscapes can be divided into two very broad categories to assist the designer in developing broad design criteria: shady landscapes and sunny landscapes. Shady landscapes are modelled after forest and woodland communities, while sunny landscapes are based on prairie and meadow communities. These two main community types should be considered when designing naturalised landscapes.

According to Harker et al (1993) the character of the forest landscape is determined predominantly by the trees and shrubs, which, due to their numbers and size, exert a strong influence on light, moisture, and wind within the community. The forest floor is frequently littered with pieces of wood and bark, leaves and other organic debris in varying stages of decomposition. This debris and humus provides sustenance for plants as well as many kinds of insects and other organisms, and makes a major contribution to the rich, loamy soils characteristic of many forest environments (Harker et al 1993).

In naturalisation, as with other restorations, the state of the site plays a significant part in the ease of design. An area containing tall shade trees with a grassy groundcover presents greater design opportunities than open sunny sites. The bright shade found beneath such trees can be ideal for growing a diversity of woodland plants. The entire areas of trees may be developed into a woodland garden, or plantings may be established as "islands" or borders centred around clustered groups of trees, with existing grass maintained as mowed pathways between the plantings. Designing a woodland landscape on open, sunny sites requires the greatest amount of time and effort, but offers the greatest opportunities for expression. On this type of site the first priority is establishing a tree cover. The types and numbers of species should reflect the model community, but may be reduced on small sites to one or two species with an underplanting of wildflowers (Harker et al 1993).

While forested communities serve as the models for treed natural landscapes, "Prairie communities serve as the models for meadow landscapes. Prairie communities are essentially sunny herbaceous landscapes dominated by grasses and forbs. They also occur in predominantly forested regions, as various sized openings in the forest, commonly called meadows or glades" (Harker et al 1993). A prairie or meadow landscape is quicker to establish than a woodland landscape, but requires just as much attention to planning, site preparation, establishment, and maintenance (Harker et al 1993).

The designer should remember that natural landscapes are composed of more than just plants; they contain organic and inorganic materials such as rocks and logs. The use of these materials in a design can serve both as substrates for plants to grow on and as interesting features in themselves (Harker et al 1993). "Natural materials can serve effectively as pathways through the naturalised landscape. Stone pathways made of native bedrock slabs blend well with naturalised plantings and are virtually indestructible. On wet sites, they should be set into a bed of gravel at least four inches deep. Other materials that make satisfactory pathways are gravel, wood chips and mosses on moist, shady sites" (Harker et al 1993).

Finally when designing the planting plan for a site it should be remembered that while the organisation of the naturalised landscape may appear to be random, it should reflect an order imposed by natural forces such as gravity, sunlight, wind, freezing, and thawing (Harker et al 1993).

Site Preparation

Site preparation is a fairly simple process. The first step is to delineate the boundaries of the planting site on the ground. Following this is the removal of competing vegetation and the preparation of the site for planting with seeds or nursery stock (Harker et al 1993). If a natural community adapted to existing conditions is selected during the design phase, the need for extensive soil improvement should be eliminated in most situations (Harker et al 1993). However, there are a number of instances where soil improvement may be required before planting can be undertaken. Where a site has been heavily debilitated by industrial or urban activities sub-soiling may be necessary to correct soil compaction caused by heavy equipment. Where a site has been under cultivation and is being restored to woodland, organic matter may need to be increased because woodland plants generally prefer a soil high in organic content. In the case of a fertile soil with poor drainage that the designer doesn't wish to work with the addition of coarse, quarried sand or gravel can improve the drainage. A variety of soil amendments may be used to improve the organic content, fertility, aeration, water retention, drainage, and structure of a substandard soil (Harker et al 1993).

After determining if soil amendments are necessary, the next step is to loosen the soil and clear it of sod, weeds, and other competing vegetation. This is required whether selecting to establish plants by seed or stock. "The elimination of weeds is particularly important when establishing an area from seed, as post-emergent weed control is difficult and marginally effective" (Harker et al 1993). There are a number of methods for removing sod from the planting site. One is to do it manually using a sod cutter. The advantage of this method is that it is quick and the sod can be stockpiled for up to several weeks for use at another location. If there is no desire to reuse the sod or the sod is of very poor quality, there are other ways to clear the planting site. Spreading a thick layer of grass clippings or other kind of mulch over the site will kill the sod, but usually requires a period of several months to be effective. Another way is to use the tilling/herbicide program as described below for perennial weeds (Harker et al 1993).

If a site is weedy rather than turfed, tilling can be used to kill weeds. For perennial weeds "A single, shallow tilling (to a maximum depth of one to four inches) may be expected to expose fewer weed seeds than repeated or deep tillings. Unfortunately, a single tilling alone is often insufficient to kill perennial weeds. If use of chemicals is not desired, repeated tilling, often for a full year, is required to eliminate weeds. While tilling may be used to break up sod and kill shallow rooted plants, it may need to be followed by one or more herbicide treatments to kill re-sprouting perennials weeds" (Harker et al 1993).

Plant establishment

There are two main methods of establishing plantings in naturalisation projects: direct seeding and the planting of nursery stock. The use of cuttings is a third method that can be used. The pros and cons of each method are discussed in the following section.

Direct Seeding

One method of plant establishment is a technique called direct seeding. The advantage of direct seeding is that most of the plants established by this technique develop in balance with their surroundings and require little or no maintenance once established (Harris 1992). Many native species can be established from seed, but it can take several years for a planting from seed to become well established (Harker et al

1993). Seeding can be an economical way to plant extensive areas that will receive minimum care and need not produce an immediate effect. It is well suited to highway and utility rights-of-way, reservoir areas, future recreation areas, urban forests, and open spaces (Chan, Harris, and Leiser, 1977 as cited by Harris, 1992).

Plants employ a number of adaptations in their seeds to improve survival that are important to the restorer interested in utilising the direct seeding technique. For instance wildflowers often have complex seed dormancy mechanisms that prevent germination of seed during unfavourable conditions. In order to break these dormancy mechanisms a period of moist cold, called moist stratification, is required. "Such species should be sown before winter for spring germination, or can be stored in a sealed container with moist sand, vermiculite or other inert material for one to two months to simulate a natural winter chilling; if the latter method is chosen the containers should be examined weekly to adjust moisture levels and to prevent moulding" (Harker et al 1993). For other species that don't employ dormancy mechanisms their seed "...must be sown fresh or germination can take years or may never occur" (Harker et al 1993).

Another concern with direct seeding is seed loss. Seed loss commonly occurs through animal predation on over-wintering seeds, rot and the displacement of seeds from the planting site by erosional forces. Seed loss can be reduced by use of a cover crop or erosion netting. Jute or other easily biodegradable material is a good substitute

(Harker et al 1993). In addition hydromulching can be used after broadcast seeding to spray a tacky material on seeded ground in place of mulch (Harker et al 1993).

The most important factor in the success of a direct seeding application is patience. Many wildflower plantings have been ploughed under because the growers were uniformed about the establishment process. It is unreasonable to expect to produce in one or two years what nature has taken hundreds of years to achieve. Establishing a wildflower meadow from seed requires several years, and during the establishment period, a wildflower planting might appear weedy (Harker et al 1993).

When implementing direct seeding as a planting technique it is tempting to have the seed mix custom formulated in order to satisfy specific design objectives; however, it is generally easier, cheaper, and more successful to utilise a commercially formulated wildflower seed mix. A commercial seed mix can vary considerably in quality, so care should be taken to choose a mix with the greatest potential for successful establishment in the planting areas. The following guidelines for selecting wildflower seed mixes were developed by researches at the National Wildflower Research Centre:

- select a mix with a high percentage of species native to the region where the seed will be planted

- Wildflower mixes should be comprised of species which bloom in the spring, summer, and fall to produce a long season of flower display.

- Indigenous native grasses, which are a dominant feature of the natural prairie or meadow community, should comprise 50 - 80 percent of the volume of a seed mix. Bunch forming native grasses provide adequate spaces in which wildflowers can become established (Harker et al 1993).

When establishing wildflowers and grasses by seed the rate of application will vary depending on the species or type of seed mix used and the sowing method. "For landscapes that are to be viewed up close, a seeding rate of six to ten seeds per square foot is recommended; for distance viewing four to five seeds per square foot may be adequate....Hydromulching can require a rate three times greater than normal" (Harker et al 1993).

Seeding early in the spring will promote fast germination of the native grasses, tender annuals, and many species of perennials in the northern and north-eastern regions where harsh winters occur; however, for perennial wildflower species that require a period of moist cold to break seed dormancy, a late fall seeding can improve germination rates (Harker et al 1993).

Before commencing sowing wildflower seed should be mixed with a carrier to increase volume and promote more even distribution of seed over the site; some carriers that have been used successfully are sand, sawdust, vermiculite, perlite, and commercial potting soil (Harker et al 1993). No matter which method of sowing is selected for a project, continuously agitating the mix during sowing will ensure the seed is more evenly distributed in the mix and on the ground (Harker et al 1993).

Wildflower seed may be sown by any of the normal seeding methods, but on smaller areas hand broadcasting is often most effective method. To ensure even coverage of the site planters should walk two sets of transects across the planting area. Half of the seed is sown walking a set of parallel transects; the second half is sown while walking a set of transects perpendicular to the first, resulting in a grid pattern of seeding (Harker et al 1993)."

A seed drill is another method of direct seeding. The advantage of this method is that a seed drill eliminates the need to till the site. By reducing site preparation activities project costs can be reduced and it is an excellent method of seeding on slopes and other erosion-prone sites (Harker et al 1993).

A third method of direct seeding is hydroseeding. In hydroseeding seed is mixed with a liquid slurry and sprayed on a site from a tanker truck or other machine. Hydroseeding is often used on sloping or otherwise difficult to seed sites (Harker et al 1993). The advantage of hydroseeding is that it allows seeds to be sprayed over distances of up to 60 meters from a machine that does not have to pass over the ground (seedbed). The latex and oil-based emulsions in the hydroseeding slurry have a stabilising effect and cause the seeds to adhere better to the ground when they land (Bradshaw et al 1980). This is a great advantage and can reduce the need for mulching.

The drawback of this technique is that "...the seeds are still much more vulnerable to variations in climate than if they were buried by traditional methods. In addition several stabilisers have been found to be toxic to germinating seedlings. With hydraulic seeding the contractor has to be prepared to come back again which is one reason why the cost is so high. The third problem is the need for adequate fertiliser and lime on acid soils "...from bitter experience it is always necessary to come once, twice or often more times in the same or subsequent seasons to provide further nitrogenous fertiliser dressings (Bradshaw et al 1980)". Adding legumes into the seed mix can reduce the fertiliser problem; however, fertiliser can restrict legume germination so mineral fertilisers should be applied after hydroseeding when utilising seed mixtures containing legumes (Bradshaw et al 1980).

Whatever sowing method is selected it is key for there to be good soil contact between soil and seed to provide anchorage and promote successful germination and growth. "To achieve good soil contact, surface sown seed can be lightly raked, pressed, or rolled into the soil. Walking on a seedbed site is often sufficient to achieve good soil contact. Care should be taken to avoid covering the seed more than one-eighth inch deep; some seeds should remain visible on the surface (Harker et al 1993)". Sufficient background information is key to successful establishment by sowing.

Establishment from cuttings

There are two methods of using cuttings to establish plant cover: sets and brush layering. Planting with sets involves the insertion of 2 to 3 metres long sticks, usually 1 or 2 year-old plant shoots, into the ground to a depth of up to one metre. On well-cultivated ground it is possible to use short sets about 25 cm long. Sets are commonly utilised as a simple and inexpensive method to establish plantings of poplars and willows. To install do not push them into the soil; rather insert them into a hole made in the earth with a crowbar and then backfill the slight space around the set with sand or a similar friable medium (Hibberd, 1989).

Brush layering, the other method of using cuttings to establish plantings, involves the use of woody branches to help stabilise both small and large fill slopes with grades of 3:1 and steeper. Properly installed, brush layering can be an effective, relatively economical solution to a variety of problems concerning slope stability and erosion.

The technique involves placing alternate layers of fill and brush along the contour of a slope. The fill layer, also called a lift, can be 0.6 to 1.5 m deep depending upon the slope. The surface of the fill on which the brush is placed should slope into the hill at least 10 degrees from the horizontal. The branches used should be approximately 1 m long for shallow fills and 2 or 3 m long for deeper fills. They are placed more or less randomly on top of each layer of fill with some criss-crossing of stems and approximately one quarter of the brush should protrude out of the completed fill slope. Branches with butts 100 mm thick or thicker can be used on the deeper fills.

Each layer of fill is compacted as it is placed. Species with flexible stems that root easily are preferred because the resulting growth gives more or less permanent slope protection. This technique can be used both as a remedial measure to curb erosion or disturbance during construction. When using it for remedial work, one may have to cut into the slope in order to place the brush deep enough. Shorter brush can be used or the brush laid diagonally. In either situation one should start at the base of the slope and work up (Harris, 1992).

Establishment from Nursery Stock

The last method of plant establishment is the use of nursery stock. This method is commonly used to establish woodland community types and smaller meadow gardens. (Harker et al 1993)

Nursery stock comes in two general types: bare-root or containerised material. Of the two, bare-root plant stock tends to be less expensive but more difficult to transplant with success whereas container grown plants usually have well developed root systems which increase the ease and success of transplanting (Harker et al 1993).

The spacing of nursery stock should in most cases follow the suggestions provided by the nursery where the plants were obtained. The ability of native plants to self propagate by seed or vegetative growth can be used in certain situations to reduce plant material and installation costs. The initial planting density can be lower than natural to allow for dispersal by seed or other means (Harker et al 1993).

When selecting a planting density for tree species caution should be used when using planting densities gleaned from industrial forestry sources. The reason behind this is that commercial timber plantings commonly use planting rates that are denser than those suitable for aesthetic and wildlife purposes. Consequently, use of these standards will require successive thinnings as the plantings mature in order to achieve the rehabilitation goals (Harker et al 1993).

Another consideration when using nursery stock of any kind is the precipitation patterns for the area in question. The general rule-of-thumb is to time plantings to take advantage of natural patterns of precipitation when irrigation will not be available. In the eastern regions of North America this means planting during the late winter and spring when rainfall is most reliable (Harker et al 1993). With spring plantings nursery stock can be installed early in the season once the ground is workable; however, if danger of hard frost is present young plants should be mulched. Alternatively planting in the early fall in warm soils allows plant roots time to grow and provide an anchoring system which prevents frost heaving during winter (Harker et al 1993).

If a quick result is desired the tree strata can be established using larger, landscape size material; however, caution should be exercised with this method as it can be prohibitively expensive on large sites, and the diversity of species available as large material may be limited. Bare root material is often used to establish tree cover on large sites, the advantages being less initial expense and the availability of a greater variety of species. Caution should be used with larger materials, as they may need staking the first year to prevent root damage from wind (Harker et al 1993).

When planting trees into an existing groundcover of grass or other species an area the diameter of the tree crown should be cleared of vegetation around each planting site and mulched subsequent to the installation of the tree. For dry sites a raised mulch border should be made around each tree to trap water. To maximise the increase in trunk diameter do not prune seedlings, particularly the lower branches of balled and burlapped or containerised trees. Understory plants should not be installed until the tree cover is sufficient to provide protective shade (Harker et al 1993).

Maintenance

The first focus of maintenance in the naturalised landscape is maintaining adequate soil moisture and controlling weeds. Irrigation is frequently required during extended dry periods in the first year after planting (Harker et al 1993). Common methods for irrigating landscapes are basin, furrow, sprinkler, soaker and frequent-low-volume systems. The application method selected depends upon the type of plantings; amount, quality and source of water; terrain; budget; and source of labour. In order to save water and labour, most intensive landscape plantings are developed with automatically controlled sprinklers or frequent-low-volume systems. With the use of any irrigation method the system should be planned and installed at the same time as the other site utilities before paving and planting take place (Harris, 1996). A formal irrigation system may not be practical for some landscapes. In these cases the restorer must rely on nature for most site moisture with the possibility of some additional irrigation conducted by hose from tanker trucks.

Weed control is often difficult to accomplish in landscapes established from seed as identification of weed seedlings may be difficult during early growth stages, and herbicides are usually not selective enough to use on weeds growing among young wildflower and grass seedlings.

Hand removal can be used effectively on smaller plantings, but is relatively labour-intensive. For larger areas mowing, spot spraying with narrow spectrum herbicides and prescribed burning are commonly used to control weeds. Mowing to a height of six inches is conducted for weed control early in the spring before the desired natives emerge. The advantage of this technique for native plantings is that it improves sun exposure for desired species and reduces weed vigour. Unfortunately mowing can only be used until the native plants attain a height of six inches.

There are a number of methods of using herbicides to control weed species in natural plantings. Wick application of herbicides is effective on weeds such as thistle, but only when they are taller than the native plants. Spot spraying of herbicides can also be used, but is usually reserved for areas where weed growth is so heavy as to prevent effective establishment of native plants. With spot spraying treated areas may have to be re-seeded when the weed problem is under control (Harker et al 1993).

Prescribed burning is another technique that is often used to control weeds and improve vigour in an established native planting. The burn should be timed to occur when cool season weeds have initiated new growth. This is in early spring through much of the Midwestern and eastern regions. The advantage of burning is that, as well as reducing weed vigour, it quickly returns nutrients to the soils (Harker et al 1993). The disadvantage is that it cannot be used with all woodland communities and hence is preferred for prairie landscapes.

One characteristic of designed native landscapes is that the landscape will evolve over time as the plants self-propagate, filling in spaces, and rearranging their positions in the spirit of competition. While this characteristic can be beneficial, it can become a problem in confined spaces. Control of this process can be achieved by either heavy mulching, which discourages self-propagation, or by hand pulling seedlings that appear in undesired locations (Harker et al 1993). Mulching is a horticultural practice commonly used to reduce weed development. Mulching consists of spreading various materials on the surface of soil to prevent weeds and conserve soil moisture. Use of mulch can also be effective in preventing frost heaving in fall plantings and in cooler climates can also be applied after the ground freezes to prevent rodents from feeding on plant parts over winter. Heavy application of mulch can discourage natural propagation;

however, so it should be used sparingly, or not at all, where self-propagation is desired (Harker et al 1993).

Ecological Restoration

Describing the differences between ecological restoration and natural landscaping is quite difficult as they are very similar in nature and the term restoration is sufficiently general to be used to describe any planting designed to improve a site, including natural landscaping (Harker et al 1993). The general use of the term restoration, however, is meant to denote the return of some degraded portion of a landscape to an improved and more natural pre-existing condition, whereas the term ecological restoration is meant to describe the art and science of recreating viable natural or ecological communities. In essence ecological restoration is an attempt to recreate nature (Harker et al 1993).

To determine if a project warrants an ecological restoration or a natural landscaping, the restorer must be guided by the project's goals. If the goal is to restore a native plant community and a complement of native species from that community will be used in a planting scheme, then it is ecological restoration. If on the other hand the goal is to use the planting of a group of native species to meet some specific aesthetic, management or design goals, the project is a natural landscaping. Generally there is a difference of intent and scale between these two actions. Whereas ecological restoration is large in scope and allows a community to evolve and natural succession to occur, natural landscaping is conduced on a smaller scale and the created landscape tends to remain at a particular managed level or state (Harker et al 1993).

Despite all of the previous advice concerning the methods for restoring destroyed and damaged landscapes to healthy, functioning natural systems, it must be pointed out that, “To restore a truly natural system is beyond the capacity and knowledge of humans” (Harker et al 1993). Be this as it may, the restorer can bring together the basic components and characteristic plant and animals of an area and, in effect, assist and direct nature through ecological restoration. The goal of this process is to encourage natural processes to take over on the site, and for missing components of the natural system to invade naturally making the restored system whole (Harker et al 1993).

There are two methods of establishing goals and evaluating the success of restoration projects. The first is to take a compositional approach and emphasise community structure and species composition within the forest. The success of these projects is measured by how closely the resulting community resembles the natural, or ‘model’ community with respect to characteristics such as relative abundance, age-class structure, spacing and distribution of particular species. The main assumption underlying this method is that if these species groupings are fairly accurately reproduced then the dynamics and functions of the communities will also resemble those of the model community (Harker et al 1993). The second method of establishing goals and evaluating the success of restoration projects is to take an ecosystem function approach. In this method the presence or absence of a particular species is secondary to ensuring that key ecological functions and processes such as nutrient cycling, erosion control, or biomass production are functioning on the site (Harker et al 1993). Following are some of the ecological systems that need to be addressed as part of the restoration to ensure success.

Reintroducing ecological processes

Site disturbance varies in severity from an ecological perspective. Vegetation destruction is a relatively minor disturbance and recovery can occur very quickly once the damaging factor has been withdrawn. In these instances it is common for the remaining fragments of the original plants to quickly shoot again using existing root systems. This process is known as secondary succession (Urbanska et al 1997). The key to the speedy recovery in the secondary succession scenario is that the soil is left predominantly intact. The state of the soil determines the speed of the succession process as it holds some of the most important non-renewable resources in the ecosystem, particularly the mineral nutrients and the soil organic matter and mineral particles that hold them (Urbanska et al 1997).

In more serious instances of site disturbance both the soil and the vegetation are destroyed or degraded to a point where the remaining soil is essentially a skeletal material composed of raw mineral fragments and particles. These pieces of rock and sand size particles are raw, and therefore the normal breakdown products such as clay minerals, as well as finer rock particles, are not present. The lack of fine particles in these soils may create an environment physically hostile to plant roots; furthermore, secondary minerals, such as the hydroxyapatites and carbonates are missing. In addition the soil organic matter and its store of available nutrients, such as nitrogen, is not present (Urbanska et al 1997). The range of possible hostile soil factors is considerable.

It is very apparent from the previous discussion that soil is a critical controlling component at the early stages of ecosystem development. However, it is also a critical controlling factor of final ecosystem development (Urbanska et al 1997).

There are three main categories of soil characteristics that will limit vegetation regeneration on these highly disturbed sites. They are, in order of significance, species immigration barriers, the physical hostility of the soil and essential resource deficiencies. As few species can overcome these challenges the process of ecosystem development may take a long time (Urbanska et al 1997). This is why "...in nature primary successions usually take 50-100 years to reach some sort of maturity and equilibrium" (Urbanska et al 1997). Human intervention can play a significant part in removing these barriers and speeding the process of succession. While impossible to develop mature woodland in less time, it is reasonable to aim for the development of a soil that is biologically active and supports a simple self-sustaining ecosystem within 5-10 years (Urbanska et al 1997).

Species Immigration barriers

According to Urbanska et al (1997) the first requirement of site restoration is the arrival and establishment of plants on site. This may seem counterintuitive, as the final goal of a restoration is to develop a sustainable plant and animal community. Nevertheless plant establishment is the first step in the restoration process because these early coloniser plants initiate a series of changes in the soil material which are important to later restoration success (Urbanska et al 1997). However, in a restoration where the ultimate goal is the restoration of ecological function, plants should not be placed where they will have no access to essential mutualists. These plants are effectively the 'living dead' as their future reproduction is impossible making their inclusion in a restoration scheme pointless (Urbanska et al 1997).

The first step in initiating plant growth on a site is to introduce plants or their propagules to the site. While plant immigration can take place naturally it can be particularly challenging in urban areas, as a migration distance of a kilometre is an insurmountable obstacle for most plants. Since natural migration can't always be relied on to supply plant propagules to a site, the introduction of appropriate species to a site is important. This is particularly important for legumes and other nitrogen fixing species due to their key role in succession and their large seed size (Urbanska et al 1997). Agricultural methods, hand seeding and planting are a number of ways of providing assistance. Even larger species, such as trees, can be established by direct seeding, although using forestry technology is usually more suitable. Another option is to bring complete pieces of the original ecosystem, rooted in blocks of original soil, onto disturbed sites in order to act as island sources of propagules (Urbanska et al 1997).

The following are six restoration approaches for developing forested ecosystems when starting from a treeless situation.

- Plant canopy trees in ultimately desired densities and proportions; mulch the ground beneath and around the trees; plant desired midstory and understory species immediately.

- Plant and mulch canopy trees as in the above approach, but plant light-loving ground cover initially (or let "weeds" grow), and add (or encourage invasion by) woodland understory and midstory later as shade develops.

- Plant trees in a savannah distribution patterns, with savannah understory. Then as shade develops, gradually plant additional trees; and finally plant (and/or manage for the natural invasion of) desired understory and midstory species.

- Plant trees in greater than ultimately desired densities and either thin or allow self-thinning as the canopy develops. Add midstory and understory species later and /or manage for natural invasion.

- Plant short-lived, fast growing trees (aspen) or tall shrubs (pagoda dogwood, alder) as a cover crop and as this canopy develops underplant with slow growing, shade tolerant, long-lived trees that will become the site dominants. Upgrade the understory as the canopy progresses, thinning the cover crop species as necessary to reduce competition with the eventual dominants.

- Do no planting: allow woody species to invade, and selectively remove those which are not desired; treat understory and midstory in a similar fashion. This is essentially the do nothing method; see the following section for details.

For most of the above methods, the herbaceous layer or strata is added after the formation of the tree canopy. The use of transplants and potted seedlings is recommended when installing the herbaceous strata; although seed has also been successfully used (Harker et al 1993).

The second terrestrial plant community commonly addressed in restoration literature is the prairie. Restorationists are most adept at establishing prairie communities because prairies have been recreated many times over and the management technique of using fire is understood (Harker et al 1993). Grassland restoration follows the general restoration steps with the consideration of the following additional points:

- Plantings can be accomplished from either seeds or greenhouse grown seedlings.
- Many prairie forb seeds require stratification (cold treatment); some also require scarification.
- Controlled burning after the third year is the most effective management option. Early spring mowing inhibits weeds and woody species.
- Collecting prairie seeds takes considerable effort. The seeds of prairie species mature at different season of the year, at different times at different locations, or a few at a time throughout the season. This means that collecting must be done a number of times at the same site
- Legumes need to be inoculated with appropriate rhizobial bacterial for the nitrogen fixing capability to develop. Other mycorrhizal fungi need to be evaluated for improving specific species functioning (Harker et al 1993)."

When using a direct seeding approach to reintroduce plants to a site the arrival of the propagules onsite is not the end of the process. Upon reaching the site a seed must overcome the physical difficulties of the raw environment and establish itself (Urbanska et al 1997). In other words they have to find themselves a "good" site. This raises the question "what is a good site?" Scientists studying the natural establishment of plants within the Mount St. Helens eruption area have found that colonisation is slowest on the coarse pumice materials and fastest on the micro-sites produced by pebbles and small rocks. This was unexpected as it was expected that the best colonisation would occur on the smooth fine materials (Urbanska et al 1997).

If using seed, it is essential prior to any seeding or planting that any serious soil compaction be relieved by ripping or scarification to allow root penetration. Compaction is a common problem on disturbances created by man and it can be alleviated using a variety of available machinery (Urbanska et al, 1997).

Once any soil compaction has been corrected the next step is to place the seed in conditions favourable to germination and establishment (i.e., a good site). The simplest way to do this is to deposit the seed below the soil surface by mechanical means, drilling or cultivation. Placing the seed below the soil surface mimics the effects of the natural disturbance and burying processes that occur in mature soils. Further protection can be provided to seed on an inhospitable substrate by placing a layer of mulch over the seed. Blowing chopped straw over the planted surface is commonly used (Urbanska et al 1997). Hydroseeding is also used (Urbanska et al 1997).

Hostility of Soil

The raw skeletal mineral fragments and particles that compose a disturbed soil may offer an environment physically hostile to plant roots because of the missing clay minerals and finer rock particles, secondary minerals, and soil organic matter. There can also be problems with heavy metal toxicity, acidity, and poor soil structure in these skeletal soils.

There are a number of techniques that the restorer can apply in an effort ameliorate many of these conditions. Unfortunately the absence of fines created by the weathering process is one for which little can be done. All the restorer can do in these situations is to attempt to speed the accumulation of these materials onsite by encouraging the presence and growth of plants. Plants are beneficial to this process through their ability to capture loose material coming from elsewhere, in effect forming miniature dunes. Even where disturbance has created a fine textured soil material plants have a role in erosion control. In these cases plants are specifically introduced early as an erosion control tool prior to the installation of the desired vegetation. Cereals such as rye, wheat or sorghum are commonly used as these 'nurse' species (Urbanska et al 1997).

Another option in those cases where a soil has been destroyed or lost is to employ an engineering solution. This means purchasing good soil from another site, transporting it to the degraded property and spreading to a suitable depth over the debilitated land. While at first glance this may seem to be an ideal solution to many of the negative aspects of soil disturbance, there are a number of drawbacks to this approach. Firstly it is an expensive technique and is generally only realistic if the area to be treated is small. Secondly, the introduced soil may not have some or all of the characteristics of the original soil requiring rehabilitation of the "good" soil. Thus it is more likely that the degraded site materials will need to be treated directly. Since we know from our studies of primary succession that this is possible, this task is likely to succeed, particularly if the restorer can harness natural successional processes (Urbanska et al 1997).

A solution to the absence of fines in a disturbed soil that may be available in specific circumstances is the amendment of the site with fine materials. Fines are often easily available as a by-product of the original degrading operation as in the case of the mica that results from kaolin extraction (Urbanska et al 1997). Fines can be introduced to the site either locally into nursery stock planting pits or uniformly spread over the site and evenly mixed into the in-situ soil material. The use of this technique can improve both water-holding capacity and nutrient retention (Urbanska et al 1997).

As noted in the soil analysis section high concentrations of heavy metals in soils can significantly reduce plant growth. What is particularly problematic for the restorer is that these elements are relatively immobile and will not leach away. Consequently metal toxicity is an almost permanent feature of the site (Urbanska et al. 1997).

There are a number of techniques for combating soil acidity and high heavy-metal concentrations in disturbed soils. One is to find acid-tolerant plant species that can thrive in the existing site conditions (Urbanska et al 1997). The downside to this technique is that it limits the plant selection pool for the rehabilitation, and the level of acidity or metal content could be high enough to effectively preclude <u>any</u> plant life from growing on the in situ material. Another technique is to treat the soil by the application of lime to reduce soil acidity to a level that is tolerable to the desired plant species. Additions of lime required to correct high acidity can range from 20 tonnes/ha to150 tonnes/ha. While this technique can be expensive it is the only option if restoration of the site material itself is to be achieved (Urbanska et al 1997). Unfortunately, applying lime to correct high acidity is not a permanent solution and must be repeated as necessary to maintain the desired effect. As such, the only permanent solution to this problem is the covering or capping of the contaminated material with another uncontaminated material. This covering material can be uncontaminated waste material obtained from the site itself, subsoil or waste from elsewhere. The layer only needs to be 30-50 cm deep to ensure that the surface is well isolated from metal contamination even on very toxic wastes (Urbanska et al 1997). If required the fertility of the covering can then be restored, by the ways already discussed previously.

All soil processes that act to improve soil structure, and particularly bulk density, will improve the available water holding capacity of the soil because this characteristic depends greatly upon the amount of pore space within the soil. The addition of organic matter to a soil is also particularly important as this material possesses an available water capacity that can be three or four times that of the mineral components of a soil (Urbanska et al 1997).

Mycorrhizal fungi also have the ability to increase soil stability and improve soil structure. This is accomplished by dint of the physical action exerted by the hyphae and the production of polysaccharides by the fungi or the associated microflora. These polysaccharides taken together with the action of fine roots (including individual mycorrhizal and saprophytic fungal hyphae) bind soil particles into larger aggregated units (Urbanska et al 1997). In addition increasing pore space within a soil permits freer passage of plant roots (Urbanska et al 1997).

Resource Deficiencies

The reestablishment of nutrient cycling to a disturbed soil is one of the keys to a successful restoration because an established ecosystem can only persist and grow if it can obtain supplies of nutrients (Urbanska et al 1997). While plant growth makes an important beneficial contribution to soil nutrient status, basic deficiencies of nutrients in raw soil cannot be ameliorated wholly by plant activities. For example a deficiency of phosphorus can completely restrict plant growth, particularly if at the same time there are other elements present which will form chemical complexes with it and make it unavailable for plant uptake. Therefore, the addition of the deficient element is necessary in these situations. Commonly an artificial fertiliser, such as superphosphate, is used or alternatively a high phosphorous organic material, such as sewage sludge, may be available. Soil analysis is needed to determine the correct amount of fertiliser to apply (Urbanska et al 1997).

Of all the plant nutrients nitrogen is probably the most important to the restorer. Its accumulation within the soil is a critical factor and must be considered during the restoration planning process because soil nitrogen is easily lost. The reason nitrogen is easily lost from soil is because it is only found in the fragile organic component of the soil and accumulates only through biological processes. In contrast most of the other plant nutrients are found in the more stable mineral component of the soil. Of the large amount of nitrogen stored as organic matter, only a small amount is released annually by mineralisation (Urbanska et al 1997).

It is clear that accumulating organic matter, both live and dead, will immediately support a variety of soil organisms, most of which have little difficulty in reaching a site. These fungi and bacteria will have an immediate effect in bringing about the decomposition of the organic matter, permitting nutrient turnover (Urbanska et al 1997). While these free living micro-organisms will fix a small amount of nitrogen (about 5 kg N/ha/yr.) the greater part of soil nitrogen is fixed by symbiotic micro-organisms such as the rhizobia occurring on members of the Leguminosae, and actinomycetes. These mycorrhizal fungi provide a direct link between the plants as primary producers and the decomposers. This direct link is in the form of the mycorrhizal fungal hyphae. These hyphae create a physical connection between the plant's root surface and soil particles and act to increase the water and nutrient absorbing surface area of the root system through the establishment of closer contact with the soil (Urbanska et al 1997).

A great deal of information on ecological succession has been gathered from the observation of the natural successional process occurring on glacial moraines located at Glacier Bay, Alaska. The Glacier Bay chronosequence demonstrated that vegetation and soil development are essentially driven by the arrival of species capable of symbiotic nitrogen fixation (Urbanska et al 1997). Therefore, soil nitrogen accumulation can also be assisted by the introduction of legumes to the site. For example studies have shown that herbaceous legumes, such as Trifolium repens and Trifolium pratense, can contribute well over 100 kg N/ha/yr. to the soils of their temperate grasslands (Urbanska et al 1997). Caution should be exercised with this method, however, if the restoration goal is to develop a low productivity high-diversity ecosystem as there is the possibility that the legume may flourish excessively and by its continuous contribution of nitrogen encourage unwanted strongly competitive species. In these situations it may be better to introduce nitrogen into the system in the form of two or three applications of fertiliser (Urbanska et al 1997).

The mycorrhizal fungi are an integral part of the soil microbiota and most families of vascular plants contain species that form at least one type of mycorrhiza (Urbanska et al 1997). Ectomycorrhizae benefit woodland plants by increasing the active area for nutrient and water absorption, and they are able to absorb and accumulate nitrogen, phosphorus, potassium, and calcium more rapidly and for longer periods than trees without ectomycorrhizae. In addition ectomycorrhizae appear to increase a tree's tolerance to drought, high soil temperatures, organic and inorganic soil toxins, and extremes of soil acidity caused by high levels of sulphur, manganese, or aluminium (Harker et al 1993).

Because of the key role of mycorrhizae in nutrient cycling the speed at which a site is restored or plant succession occurs can be hastened by manipulation of the mycorrhizal fungus population or undertaking inoculation programmes (Urbanska, et al, 1997). The dominant mycorrhiza in a region varies according to latitude or altitude, prevailing climate, and soil types (Urbanska et al 1997). Consequently, when planning the reintroduction of mycorrhiza fungi to a disturbed site it is key that the correct mycorrhiza fungi for the region is selected/obtained.

Topsoil stockpiling is a valuable tool for the management of soil mycorrhizae as the topsoil is the primary source of mycorrhizal inoculum (Urbanska et al 1997). Of course, to use this technique the restorer must be involved in the project right from the conceptual stage in order to permit for the planning of soil striping and stockpiling. It is important to note, however, that topsoil-stocking techniques can have a significant impact on the survival of fungal propagules. Other studies have found that the moisture content of stockpile soil is key to the survival of AM fungal propagules. Specifically the drier the soil, the higher the remaining mycorrhizal infection potential (Urbanska et al 1997).

In the absence of topsoil the development of mycorrhizae on spoil or tailings can be quite slow. In the event that topsoil is unavailable the amendment of the soil with organics may enhance mycorrhiza function (Urbanska et al 1997).

One method of mycorrhizae inoculation is the use of inoculated nursery stock. There are three methods to inoculating nursery seedlings; 1) using whole soil from established plant communities, 2) using pieces of chopped infected root, and 3) using spores of the fungi (Harker et al 1993). Studies have shown that "...inoculation of the seedlings to be used for revegetation with selected mycorrhizal fungi (and rhizobia) improved outplanting performance, plant survival, and biomass development" (Urbanska et al 1997).

Inoculation is not only appropriate for severely disturbed sites. It may also be necessary for the rehabilitation lightly disturbed soils "...in which the return of effective mycorrhizal fungi would be too slow to ensure establishment of a diverse range of plant species before canopy closure" (Urbanska et al 1997). Nursery stock can be inoculated prior to planting by being grown in a suitable soil, but inoculating seed material is more difficult because the process is not well understood. In these cases the scattering of appropriate soil as an inoculum may be the only practical solution (Urbanska et al 1997).

Nitrogen can be easily introduced to the soil through the application of mineral fertilisers. When using this method it is important that the rate of fertiliser application be matched to the rate of plant uptake - approximately 100 kg/ha/yr. Using a more costly slow-release fertiliser will reduce the likelihood of leaching (Urbanska et al 1997). Again, heavy applications of nitrogen-rich organic matter can be used in place of mineral fertiliser where suitable (Urbanska et al 1997). Digested sewage sludge is becoming increasingly popular in this role. This is because a one application of this material can provide the entire soil nitrogen requirement as well as substantial amounts of phosphorous all in a form that is readily available to plants and leach resistant (Urbanska et al 1997).

The introduction of earthworms in soil or turf can have startling effects on drainage and litter accumulation. Unfortunately, they have little mobility and must be introduced to a site in most cases. Where introduction is being attempted the restorer must note that, as with the microorganisms, soil chemical conditions must be suitable for the introduction to be successful (Urbanska et al 1997).

Monitoring Success

A tool is required to determine how successful restoration activities are. One way to determine restoration success in enhancing soil processes is to track the ratio of soil microbial respirations to total microbial biomass on the restored landscape (Urbanska et al 1997). Successful restorations should be accompanied by a rise in soil microbial respiration, an even greater increase in microbial biomass and an exponential decrease in the metabolic quotient (i.e., qCo_2) (Urbanska et al 1997). In addition, changes in the physical and chemical characteristics of the soil should be observable over time. These consist of a steady decrease in the percentage of sand in the 2mm fraction of the soil and a considerable rise in soil organic carbon and total nitrogen content (Urbanska et al 1997). These attributes are potential ecological bell weathers and may be incorporated into a monitoring program to measure ecological activity in a soil and, consequently, restoration performance.

Soil fertility and habitat diversity

Many ecologically valuable areas of highly diverse vegetation are associated with infertile soils. In fact "...there is a wealth of observational and experimental evidence to show that high nutrient supplies reduce species-diversity and encourage the growth of more 'competitive' species" (Buckley, 1989). To conserve these communities, management is required.

Little research has been conducted on the deliberate impoverishment of soils to re-create semi-natural communities. With so little information restorers are only able to speculate on the general principles involved, and make educated guesses at optimal methodologies and time-scales of treatment required. There are two main methods to reduce soil fertility through human agency: The first is the use of management strategies to reduce total soil nutrient capital by promoting a net nutrient export. The second is to reduce available nutrient pools by encouraging the sequestering of nutrients in unavailable pools and blocking or reducing further circulation to a low level. We can classify the management strategies used to achieve these two methods into the following (after Buckley 1989):

1) Promoting natural processes that impoverish nutrient supply,
2) Indirect removal via continuous cropping, and
3) Direct soil nutrient pool removal (Buckley, 1989).

Promoting natural processes that impoverish nutrient supply is a set of strategies composed of management practices that promote natural soil degradation processes such as leaching and incorporation of low decomposition rate organic materials. In addition the following three management practices will promote natural soil degradation (after Buckly 1989):

1) Use of natural early-successional development,
2) Plantings of native soil impoverishing species, and
3) Continuous fallowing.

The second strategy is indirect removal by continuous cropping. Here repeated crop production is used without fertilisation or fallowing to reduce soil nutrient status. There are two main problems with this technique. The first is that the cropping must result in a net removal of nutrients. The second is that the effect of continuous cropping becomes less successful as the nutrient pool declines. This means that, should the management objective have not been achieved, it will then become economically difficult to justify further treatment due to the law of diminishing returns (Buckley, 1989).

The third and last method is the direct removal of soil nutrient pools. This seemingly drastic method utilises techniques such as topsoil stripping to expose less fertile subsoils to reduce soil nutrient status. While this technique appears at first sight to be rather extreme, it is only slightly more severe than conservation practices already carried out in some areas. In fact on agricultural soils surface stripping may be on of the best alternative (Buckley, 1989 40). Diluting the fertile surface layers of a soil profile via deep plowing is another option available (Buckley, 1989*)*.

Plants & animals

When planning the restoration of a disturbed site focusing "...on the principles of plant-animal mutualisms can improve both demographic functioning of an ecological restoration, and also the economic balance sheet that is integral to projects aimed at improving our natural areas" (Urbanska et al 1997). Effective protocols will yield communities that will be sustainable, with minimal human intervention and management (Urbanska et al 1997). There are two aspects of plant animal interaction which are key in ecological restoration, particularly where the intent is to use natural processes to help the process along; they are pollination and seed dispersal.

Pollination

A focus on plant-animal mutualisms is important in restoration because the inclusion of a species of plant in a restoration plan does not guarantee the attraction of pollinators in sufficient abundance or diversity to ensure adequate seed set. This failure to achieve abundant seed set may lead to the failure of the plant to increase its numbers within the site and to spread throughout the desired space (Urbanska et al 1997). Obviously this can be a significant problem in those restorations where the intent is to use the natural successional process to achieve the restoration goals.

When taking plant-animal mutualisms into consideration during restoration planning the restorer must ensure the match between the installed plant species and the habitat's pollination guild. When doing this there are two main questions with respect to pollinators: do the existing pollinators visiting the plants in the first few years produce seed; and what is the probability that the developing guild will be similar to the pollinators typical of the target plant community on undisturbed sites? In temperate North America Queen bumblebees (*Bombus spp.)* are often the only large insects flying on the chilly days in the early spring and that, consequently, they pollinate many early spring flowering herbs. It is also the case that other spring plants require visits by solitary bees (*Andrenidae*) for pollination and that later in the season other plants have floral traits that attract migrating hummingbirds. The implication of this knowledge is that the physical habitat of the restoration must be appropriate for these required mutualists, as well as for the plants in order to achieve successful pollination (Urbanska et al 1997). From the above it is clear that, in temperate regions, "...a restoration of spring woodland plants might be pollinator-limited if isolated from land where bumble-bee colonies are not quickly founded" (Urbanska et al 1997). Since Queen bumblebees establish their new nests in existing holes in the ground, such as those made by rodents or rotting wood, the restorer must ensure that holes of this type are present on site. Should they not be present the restorer must artificially provide them (Urbanska et al 1997). Consequently plantings of spring flowers that require visits by queen bumblebees need to be placed near nests to have any chance of pollination (Urbanska et al 1997).

Another consideration for the restorer is the likelihood of bees entering an area. It is known that the larger social bees can travel long distances on their foraging (up to 8 km), but they focus on the more desirable species within an area which means that smaller flowered species may be ignored. Unfortunately, little is known about the behaviour of the smaller bee species (Urbanska et al 1997). In order to ensure that all plants within a restoration site receive visits from the key pollinators it is important that these species establish themselves within a site. Unfortunately, natural invasion of a site by these species may take many years and be difficult to guarantee. One way in which it may be possible to induce these species to come into the area is to install small patches of artificial habitats for some important bee pollinators on the site (Urbanska et al 1997).

The interplay between number of available pollinators and number of nectar-rewarding plants on the restoration site is another issue that must be considered as part of the restoration planning. Observations have shown that where the abundance of pollinators is low relative to the number of flowers, many flowers fail to set seed. The converse is also true (Urbanska et al 1997). A good example of this is studies of Viscaria vulgaris and Dianthus deltoides in Europe. These have shown that larger populations of these species receive significantly more pollinator visits and set more seed than smaller or fragmented stands (Urbanska et al 1997). Despite the above, ecologists have a poor understanding of how insect and plant populations interact to optimise reproduction so the cautious restoration should avoid extremely large or small stands of single species in their plans (Urbanska et al 1997).

The restorer must also be aware that the microsite within which a plant is located may also affect its attractiveness to pollinators. One reason for this is that many insects are restricted to narrow portions of larger landscapes. For example geometrid moths prefer the cover of woods, and only forage at the edge of fields which results in only those plants located on field edges being visited and pollinated (Urbanska et al. 1997). The physical characteristic of the microsite is another reason some microsites are more attractive to pollinators. This is demonstrated by the finding that seed production is often confined to sunnier microsites. One reason for this is because flowers in the sunny microsites have several-fold more visits by pollinators. If wildflower seed set and population spread is an immediate restoration goal when restoring a woodland, the installation plans must concentrate on microsites that are attractive to the associated pollinator guild rather than following a regular grid as used in most ornamental plantings (Urbanska et al 1997).

Another potential problem in restoration is competition between various plant species for pollinators. This can be relieved by planning for the construction of, as far as is possible, communities of sequentially flowering species (Urbanska et al 1997). Planning for sequential flowering is also prudent for those situations where the local pollinator guild is poorly known as it will increase the probability that some fraction of the plant community can be visited by the local pollinators (Urbanska et al 1997).

Incomplete knowledge of the precise pollinator guild for all plant species in the restoration can be a significant problem for the restorer. Even in this situation the restorer should still attempt to address the question of pollinators as part of the restoration for "...important groups of pollinators can usually be determined by the floral syndrome, or the suite of characters, that is associated with major classes of floral visitors" (Urbanska et al 1997). Furthermore, the ease of developing mutualistic relationships with pollinating species is heavily influenced by the characteristics of the flowers produced by the species selected as part of the restoration. Some flower structures allow wide ranges of species to pollinate, while others are more restricted. Many different insects can successfully pollinate plant species with generalised, open, radially symmetrical flower shapes, whereas plants that have an intricate zygomorphic floral shape will allow only a restricted spectrum of pollinators (Urbanska et al 1997). One way for the restorer to overcome ignorance of the appropriate pollinator guilds for a species is to introduce mainly species with the generalised floral characteristics that will maximise pollination success.

Seed Dispersal

The other key role of organisms in plant ecology is seed dispersal. While it is possible to incrementally add seed to a site throughout the term of the restoration in order to aid in the maturation of a project, an alternative option open to the restorer is to take advantage of the actions and behaviour of natural dispersers to spread seed. Using these natural dispersers provides the restorer with free assistance that spans many years. In fact the activities of seed-dispersers may eventually make them the primary determinant of which species of plants predominate on the site, and how they are distributed (Urbanska et al 1997). It should be pointed out that not all plants require mutualists to disperse their seeds. Most gymnosperms, and the wind-dispersed angiosperms, rely on the vagaries of wind speed and direction to spread their seed (Urbanska et al 1997).

There are many different species which act as dispersers. Birds, bats and other mammals, reptiles and even fish participate in these mutualisms in various habitats, but invertebrates, especially ants, can also play a major role in dispersal in some areas, one example being temperate woodland forests (Urbanska et al 1997). While animals do have a role in seed dispersal, it is generally a diffuse mutualism and there are few known examples where only one animal species is the sole agent for a plant species (Urbanska et al 1997).

There are two characteristic seed dispersal processes that play a part in restoring disturbed sites. The first process is the removal and deposition of seeds from the plants introduced by the restorer. This type of activity is important as it increases population size and local range, and begins the slow development of an age-distribution and genetic structure in the restored population that is typical for the species. The second type of seed dispersal process is the introduction of seeds to the site from surrounding vegetation. This process may bring new species to the community and can act as an agent of demographic change in the installed plants. This immigration process can be beneficial or detrimental to the restoration process. Immigration is beneficial by adding species and genotypes that are typical of local native plant communities, including those which may not be available from nurseries to the site. However, the drawback of the immigration process is that it can introduce unwanted species, such as exotics, to the restoration site where they may displace desirable native species. The removal of these exotic plants must become part of the management regime until the threat of invasion is curbed. It may be the case that the threat of invasion never subsides requiring a constant, low-level management (Urbanska et al 1997).

Increasing the probability of a large number of visits to the site by seed dispersers can increase seed dispersion on a site. One successful technique to achieve this is by increasing the amount of perching space for visiting birds. The use of perches was suggested by studies that found seed rain from birds was highest in mature shrub, and not into adjacent grasslands (Urbanska et al 1997). Where cover is absent, the use of perches has been shown to significantly increase the number of seeds deposited on a restoration site. A suitable height for an attracting structure is two metres (Urbanska et al 1997).

Another technique thought to improve seed dispersal is the use of attractor plants. This method consists of planting early successional woody plants that produce large displays of fruit in the hope that these species will maximise the quality of the plant lure for , and therefore site visits by, birds. This increases the number of seed introduced to the site (Urbanska et al 1997).

A third method may be to vary the vertical and horizontal distribution of plants across the landscape. This technique is based on the findings of an experiment in which woody species were planted in patches of four different sizes. The results demonstrated that, although the largest patches received more seed in total, the average seed number per trap was highest in the smallest patch. In fact many frugivores (an animal, that feeds primarily on fruit.[1]) and flocks of birds will congregate even on patches of only 7 plants. These results suggest that the installation of nucleating centres may initiate the successional process on barren restoration sites (Urbanska et al 1997).

Finally in restorations that utilise mutualistic relationships secondary phases of restoration may be necessary. This stems from the fact that not all mutualists are attracted to a sunny open, raw site. For example the ant foragers, an important seed distribution agent for many woodland species, will only enter a habitat after the site's soil has developed a structure favourable for ant nests. Since a certain amount of biological activity has to occur onsite before this agent will appear, the introduction of herbs that are dependent upon ants for seed dispersal (myrmecochores) must be done at a later date for restoration to be effective (Urbanska et al 1997).

Managed Succession

One low intervention option available to the restorer is to just leave the site alone and allow the natural course of plant and animal invasions and extinctions to occur or to manage this process of succession to achieve desired results (Harker et al 1993). This low or no intervention strategy is based on the knowledge that plant communities change over time through a process known as succession (Harker et al 1993). Through succession the natural processes of soil and ecosystem development will occur to create improved site conditions and a properly functioning and structured ecosystem (Urbanska et al,). Succession is attractive to the restorer because it is "...always waiting to happen, even on most extreme materials, whether glacial moraines, lava flows, derelict quarries or disused railway lines" (Buckley, 1989).

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There are two broad categories of succession; primary and secondary. In essence primary succession is the development of a functioning ecosystem commencing from a blank slate. Raw soils left behind by retreating glaciers or newly formed volcanic islands are sites of primary succession. Landscapes debilitated by human industrial activity such as strip mining are also sites of primary succession. Primary succession can achieve remarkable results very quickly - complete forest cover in less than 100 years in most cases. This metamorphosis occurs due to allogenic factors originating outside the plant and animal community, and to autogenic factors arising from within acting to progressively improve the habitat and therefore allow the plant and animal community to develop a progressively greater complexity, biomass and activity (Buckley, 1989).

Secondary succession is quite different from primary succession. Whereas primary succession starts from a skeletal soil, a secondary succession occurs on a site where the previously existing ecosystem was catastrophically disturbed. The key factor in these situations is that, while damaged, the ecosystem is not wholly destroyed. Despite the catastrophic loss of vegetation associated with the disturbance, the soil is left essentially intact. This does not mean that there is no damage to the soil in these situations. The damage that occurs in these situations is not usually serious from the point of view of a functioning ecosystem. What is important is that the soil holds some of the most important non-renewable resources in the ecosystem, particularly the mineral nutrients and the soil organic matter and mineral particles that hold them. Consequently if the soil component of the ecosystem remains, the original species can quickly make a new start as the vegetation can regenerate without delay. This is the essence of secondary succession (Urbanska et al 1993).

Scientific thought on the process of succession is constantly evolving. Initially successional theory pioneers proposed a model for primary succession comprised of a colonisation step which was subsequently followed by a series of increasingly complex habitat interaction stages that lead to a climax community restricted from progressing any further by climatic or soil related factors (Harris et al, 1996). One of the important recent changes in successional theory is the move to view ecosystems as not in balance, but rather as systems in flux from some scale or perspective (Urbanska et al 1993).

The implication of this new thinking to ecological restoration is that any particular site results from the historically unique combination of process for that location, which is referred to as contingency (Urbanska et al 1997). For the restorer this concept of contingency creates a significant problem: how does one form objectives for a site when there is no one consistently predictable climax community for a site, but rather a number of options which will reflect the history of the site? As a result restorers have found that to "...provide objectives for restoration projects, it is critical to decide on reference conditions. In the absence of one ideal reference state for any type of community or ecosystem the restorer instead uses the context and history of the site to determine valid reference states" (Urbanska et al 1997).

Determining the objectives for a restoration is an important step in the process as it determines how to manage the succession (if at all) and how much planning, money, time and effort will be required. Essentially there are two ways to go about using succession. The first is to ensure the site has everything it needs to achieve a successful stable end community. This requires that the site be made suitable for general vegetative growth and that a sufficient supply of plant propagules appropriate to the area be made available. Any management would focus on ensuring that the site conditions remain conducive to plant growth and on the removal of noxious weeds and alien species. The second method is much more focused. It requires that the site be made suitable for a specific community type, that the plant propagules specific to the desired community be introduced and that sufficient artificial management be provided to ensure that the desired community thrives on the site.

Successional Management

Luken (in Harker et al 1993) proposed a three-step succession management model. The three steps are designed disturbance, controlled colonisation, and controlled species performance. It is in the designed disturbance step in this model where activities designed to create or eliminate site availability are implemented (Harker et al 1993). This first step is one of the most important as successful restoration depends on the treatment of all the soil problems - physical, nutrient and toxicity factors - as well as the biological problems set by the species themselves (Buckley 1989).

The most important site problem to overcome, and the problem where failure to provide successful treatment is most common, is lack of nitrogen. Inadequate nitrogen supply is one of the main reasons for restoration failure because a great deal of nitrogen must be accumulated in a soil to provide an appropriate capital from which adequate supplies of mineral N can be released annually by mineralisation. Furthermore, the more advanced and productive the community, the greater is the amount of nitrogen required, which may present problems (Buckley 1989). There are many situations where nutrient addition is important to ensure effective restoration of damaged communities (Buckley 1989).

In addition we know that there is a correlation between species number and pH (Harris et al 1996). Where pH is low there will be little succession and colonisation will be by those plants that can tolerate low pH only (Harris et al 1996). Where pH is not limiting, colonisation will follow a successional pattern with species composition dominated by local species (Harris et al 1996).

Luken's second step, controlled colonisation, includes methods used to decrease or enhance availability and establishment of specific plant species. In other words, methods to introduce or remove species from the site. Colonisation is controlled by two factors: the propagule pool (i.e., the supply of seeds, spores, rootstocks, bulbs, stumps, rhizomes, plant fragments, and entire plants) and the initial floristics of a site (Harker et al 1993).

One of the first solutions is to introduce the correct species to a disturbed area at the outset. This is generally not difficult where a restoration uses only a few species. When using complex commercial species mixes, however, there may be species included unwittingly within the seed mix which are aggressive or have crucial facilitation effects (Buckley 1989).

It is also critical to ensure the absence of aggressive weed species from the project site. Despite the best efforts of the restorer to select a seed mix, aggressive, inappropriate species may already be present in the site. In fact this situation is almost inevitable when using topsoil, unless the restorer is very careful, because the supply of topsoil is very uncontrolled (Buckley 1989).

A third technique is to rely on lack of immigrants. This is essentially a passive technique that relies on the absence of invader species from the vicinity in any numbers that could cause problems. For instance this situation is highly likely where the restoration involves an extremely open community in an arable situation and tree and shrub species would be unwelcome invaders. However, where suitable seed sources are available colonisation can be very rapid which makes this an imperfect method (Buckley 1989).

The final step in Luken's model, controlled species performance, is essentially the management part of the model and includes methods that can be applied to decrease or enhance the growth and reproduction of specific plant species. It is important in this management model to take care to avoid harming the desired community when removing undesirable species (Harker et al 1993).

Methods of Control

There are a number of techniques available to the restorer to control the performance of plants within the subject site. The natural competition between plants for suitable sites can be used to exclude unwanted species. This relies on the fact that the growth of desired species can, at least temporarily, exclude unwanted invaders (Buckley 1989).

The proper restriction of soil fertility is another practical technique. The use of this method assumes that the goal of the restoration is to develop the type of species rich community that commonly develops on low fertility soils. For further details of this technique see the discussion in the previous section.

The restorer can also rely on the action of other site factors. This technique requires that the restorer recognise those site factors, such as drainage and soil texture, which can have important controlling effects on plant communities and to use them to their best advantage as part of the restoration plan to reduce competition from unwanted species (Buckley 1989).

Cutting and grazing are two management techniques that restrict plant growth and consequently competition. While cutting does not always produce the same results as grazing due to its non-selectivity, it is an effective grazing substitute. In addition the removal of cuttings from the site will remove some nutrients and result in a lowering of fertility (Buckley 1989). This is also discussed in detail in the previous section.

Burning can be an important alternative to cutting and grazing when cost or ease of implementation hinders their use. While burning does not have the same detailed effects as cutting and grazing, it is a powerful method for preventing succession, and appropriate for particular plant communities such as heathland. One drawback of this technique is that it results in the loss of nitrogen and sulphur from the system, although the amount is minor when compared to amounts already in store (Buckley 1989).

Finally, if the previously mentioned techniques cannot be implemented or are ineffective in their ability to restrict successional change, the technique of last resort is the removal of the offending species in their entirety by hand or machine. While this is a very positive method it is extreme and laborious. Another alternative is the cutting of individual species. Unfortunately, with this method regeneration from stumps, especially for tree and shrub species, can only make the situation worse. Herbicides are a very positive alternative, however, their extensive, rather than selective use, requires great care in their choice and application. Their use in a more selective, spot treatment basis where uncritical application is less likely to cause trouble, may be much better. Whichever method is selected, herbicides are expensive and troublesome to use.

RECOMMENDED SITE TREATMENT

As mentioned in the introduction the development of a comprehensive rehabilitation prescription for the site in question is beyond the scope of this study. There are two main reasons for this. Firstly the level of soil sampling on the site was not sufficiently rigorous to determine precisely the extent of the lead and cadmium contamination. Secondly there was some question in the author's mind concerning how pristine a landscape the City wanted to create on the site. There are two main options; the first is to accurately model an actual ecosystem or plant community found in the wild on the site. The other is to be more pragmatic and create a hybrid landscape unique to the site. The City's waterfront vision report did not go into sufficient detail to determine which general approache is preferred. Since each approach will dictate different management techniques, the author will only make recommendations on the appropriate rehabilitation methodology based on the site conditions, the rehabilitation management team, and the general framework of a rehabilitation prescription and post management plan.

The decision on how to proceed with the restoration of the subject property is difficult due to the finding of localised high lead and cadmium readings on the site. With the visible success of natural regeneration on the subject land, the existence of well established and outwardly healthy ornamental vegetation in localised areas, and community goals concerning natural rehabilitation, the managed succession approach would be an ideal technique for this restoration project. Unfortunately, lead and cadmium contamination, where untreated, poses a risk of negative impacts on human, animal and plant health. Because heavy metals are very immobile there are two treatment options; cap the site with clean fill or excavate the contaminated soil, dispose of and replace with clean fill. No matter which option is selected it will set back the process of natural succession by the destruction of any plants that have been established over the contaminated areas. Due to the new fill required by either of these options, the managed succession approach may not be suitable for the entire the property.

Due to the complexity of restoration work and its multidisciplinary nature it is recommended that the City of Thunder Bay select a multidisciplinary management team for this project consisting of a biologist, landscape architect and bio-engineer experienced in slope and stream bank stabilisation projects. The team should be given a mandate to consult with communities of interest, develop a detailed site design and rehabilitation plan and oversee the actual restoration work. It is felt that these professions should cover the main areas of expertise required to develop and implement the final restoration plan. Other expertise should be obtained as required.

Soil Treatment

As noted earlier, the localised presence of high lead concentrations in the soil is the most serious physical or chemical problem with the in situ soil. When the extent of the lead contamination is determined by additional sampling and testing the contaminated areas should be treated. Due to the immobility of lead the only treatment is to cap the in situ soil material with clean fill to a minimum depth of 30-50 cm or to remove the contaminated soil and replace with clean fill. The use of a sand or sandy loam textured material for capping or replacement is recommended in order to maintain the consistency of the site's soil texture, and the existing drainage pattern and moisture regime. Because of the challenge of disposing of contaminated materials it is felt that the capping solution is the best option available to the City. A similar process should be utilised for the isolated areas of cadmium contamination.

Prior to the placement of the fill cap the bark pile left behind by the previous milling activity should be stripped from the site in order to reduce the risk of any possible settling in the future and to utilise this source of organic matter as a soil amendment for the new soil material. The analysis of samples taken from this organic material found this material to have lead concentrations within the acceptable limits. To confirm this information it is recommended that the material be randomly sampled and tested for lead content in a more thorough manner during the removal phase to confirm its suitability for use as a soil amendment. If the concentrations are within acceptable this material should stockpiled, mechanically ground into a finer material (if required) and composted. Then any localised compaction on the site should be relieved by deep plowing (to a minimum depth of 50cm) and then graded to create a suitable topography.

After treating the site for the lead contamination, grading to create the final topography and removing compaction by plowing, the organic amendments should be added. Figure 7 demonstrated that the CEC for much of the property was significantly lower than what is considered normal for temperate soils. Amending the soil with organic matter will improve the CEC, as well as the available water holding capacity, and structure of the new and existing soil. Care should be taken that the break down of this organic material by soil microorganisms does not rob the soil of nitrogen. To reduce this likelihood chemical or organic nitrogen should be added to the soil.

In addition to the localised high lead and cadmium concentrations, the soil analysis found a deficiency of nitrogen, potassium and manganese on the site. If appropriate for the final management goal, these deficiencies should be corrected by the addition of an appropriate fertiliser. It is key that fertiliser application within close proximity to the river be controlled to prevent water contamination. When using chemical fertilisers, hand application is one way to control application and prevent direct contamination of the river. Another option is the use of slow release chemical formulas or organic fertilisers.

Restoring the natural flora and fauna of a soil is necessary to re-establish nutrient cycling in a degraded soil. Many of the bacteria and fungi that decompose soil organic material will readily colonise a disturbed soil; however, the mycorrhizal fungi do not invade a site as readily. As part of the process of returning natural nutrient cycling to the site there is a need to return appropriate flora and fauna to the soil. This can be done through the inoculation of seed or planting stock during the planting process. See the revegetation section for more details.

Facilities Construction:

Once the major soil problems are addressed the next step in the process is to construct any desired facilities and install any required infrastructure. The first task is to implement measures to control unauthorised vehicular access to the property through the installation of fencing, bollards, or other some other physical barrier. This is necessary, as there is currently uncontrolled vehicle access to the site that has created sterile areas believed to be the product of soil compaction. Then any other infrastructures needs should be addressed. Some important requirements are parking, paths, bridges, shelters/pavilions, benches, utilities and restrooms.

At the same time any slope and bank stability works should be completed. One specific need is to stabilise the areas of active erosion along the south bank of the Current River. Traditionally stream flow and wave induced erosion have been controlled by structural devices like rip rap, retaining walls and sheet piles. These techniques are commonly expensive, ineffective or socially unacceptable. An alternative or complimentary approach is bioengineering. Bioengineering is a method of construction utilising live plants alone or combined with dead organic or inorganic materials to produce living functioning systems to prevent erosion control sediment and provide habitat. There are a number of possible bioengineering solutions to this problem such as interplanting rip rap, coir fascines, and brush matting (Franti 1999). The advantage of using bioengineering solution is low cost and lower long-term maintenance costs, low maintenance once plants established, environmental benefits of wildlife habitat, water quality and improved aesthetics; improved strength over time with root development; and compatibility with environmentally sensitive sites (Franti 1999). The experience of the author is insufficient to identify the best technique for the situation and as such it is recommend that professional bioengineer be hired to advise on the most appropriate erosion control techniques for these circumstances.

Revegetation:

In the City's waterfront vision report two of the main goals for waterfront development were to improve public access and return nature to the harbour. It is felt that the creation of two main plant communities on the site, forest and meadow, will meet these broad community goals, the recommended program and design elements, and work best with the site's physical characteristics. In addition it is recommended that existing marsh areas be enhanced or expanded. See Figure 24 for a graphic of the general community breakdown. This distribution is proposed because it reflects the current vegetative community types that developed in harmony with the site through the process of natural succession, it will provide visual access to the harbour, and will create diversity on the site through the mix of plant communities.

Forest Landscape:

As noted in previous sections of this report there are a number of options available to the restorer to create landscapes dominated by trees. The first aspect of the landscape that must be determined is what type or stage of forested landscape is desired. Birch, poplar and pine are slowly re-establishing themselves on the site and, if left alone or assisted, will result in a mixed forest of this composition in the short term. Over the longer term this forest will yield to one made up of the shade tolerant conifers such as white spruce and balsam fir. Because of the heavy impact that spruce bud worm (*Choristoneura fumiferana* - Clemens) has had on the health of these tree in local parks, they are not ideally suited to maintaining a long lived, healthy, vibrant forest. If the community wants a forest composed of other longer lived species such as larch, cedar and red and white pine a planting program and more intensive stand management will be required. While allowing nature to take its course on the property is attractive financially and ecologically, it is strongly felt that the establishment of a long lived pathogen resistant forest is the best option for the City. The main reason for this is the location of the land, and the fact it is one of the few publicly owned pieces of publicly accessible open space on the waterfront. This does not mean that existing areas of regeneration cannot be maintained on site – it means that they should not be allowed to dominate the site. This naturalisation approach also allows for the maintenance of the ornamental trees planted in the arboretum by a previous owner. Areas which are to be kept as part of the development should be identified in the field by flagging and protected by snow fencing to ensure their survival during the soil amendment and utility installation phase of the project.

Based on this discussion it is recommended that the tree species used in the restoration of the Current River site be limited to white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), tamarack (*Larix laricina* (Du Roi) K. Koch), eastern white cedar (*Thuja occidentalis* L.), jack pine (*Pinus banksiana* Lamb.), the poplars (Populus grandidentata and Populus tremuloides), and paper birch (*Betula papyrifera* Marsh.). Additionally a number of secondary tree and shrub species should be encouraged on the site because they are suited to particular site conditions or provide valuable ecological functions. Alders should be encouraged for their nitrogen fixation function and ability to thrive in riparian areas and American mountain ash (*Sorbus americana* Marsh.) should be planted as its berries act as an attractant for seed dispersers. Black ash (*Fraxinus nigra* Marsh.) should also be encouraged for its ability to thrive in riparian zones. This list does not preclude the use of trees already growing on site. The ornamental plantings near the site of the pulp mill and the existing natural regeneration of birch and poplar should be incorporated into the forest where practicable.

Now that we have determined the general approach and selected the mix of species for establishment on the site, the next step is to determine how to go about establishing the desired forest. Since the main goal is the establishment of specific species in the canopy an approach that is biased towards canopy establishment should be utilised. It is recommended that the canopy trees should be planted first at the desired densities and proportions with a light loving ground cover (or weeds). The trees should be mulched and over time as the canopy develops the desired woodland understory species should be planted or their invasion encouraged. In addition specific plantings of desired attractor species, nitrogen fixers and riparian species should be undertaken as well.

Meadow Landscape:

As the site exists today, a significant proportion of the land on the south bank of the Current River is covered by a meadow heavily dominated by grass interspersed with concentrations of herbaceous species such as Canada goldenrod, fireweed (*Epilobium angustifolium* L.), pearly everlasting, yarrow (*Achillea millefolium* L.) and the common strawberry. These species indicate that this portion of the site is a dry, disturbed low nutrient landscape. Since it is proposed that the existing soil status be maintained through the restoration process, the creation of a dry meadow on this area has the highest likelihood of success and will be the most cost effective. Schedule A contains a list of the herb species observed onsite. It is recommended that this list be used in consultation with a local seed distributor to select a pre-mixed commercial seed mix that is appropriate for local conditions. Selecting a seed mix that contains a higher proportion of species that produce generalised, radially symmetrical flowers will maximise the number of mutualists that will be able to pollinate the meadow species. As discussed previously this is vital if the landscape is to be self-sustaining and if natural succession is to be used as a management tool to establish meadow on debilitated areas. Indigenous bunch forming grasses should compose 50-80% of the mix (as measured by volume) with the remainder of the mix composed of native herbaceous species that bloom throughout the growing season.

Unlike the case of forest landscapes, seeding is an appropriate technique for introducing meadow species propagules to the restoration site because these communities are dominated by herbaceous species and grasses that establish relatively quickly compared to forests. As mentioned previously existing meadow vegetation already covers much of the proposed meadow landscape. Some of this meadow may survive the lead and cadmium remediation process, compaction relief and subsequent site grading. Where this is the case, and assuming the surviving area is composed of desirable species, these areas should be maintained as propagule pools. Then the areas covered by the new soil caps and compacted areas that have been plowed should be seeded with the selected mix. Because the site is small seeding should be by hand using the two transect method. The seed should be sown in the spring at a rate of 6 to 10 seeds per square foot, as this meadow will be viewed at close proximity. Sawdust or a commercial potting soil should be utilised as a carrier because they will serve the additional function of increasing the organic content of the soil when their seeding role is complete. The seed should be stratified prior to seeding to maximise germination success and inoculated with the appropriate mycorrhiza fungus because of the great benefit of this mutualist to the cycling and uptake of nutrients and moisture. To reduce seed loss after sowing, mulch with an easily biodegradable material such as straw. If a significant area of the existing meadow survives the soil treatment phase, consideration should be given to mowing these areas prior to seeding in order to reduce weed competition.

Plant-Animal Mutualisms:

Plant and animal mutualisms are important on a site to ensure the pollination of introduced plant species on a restoration site. Unfortunately, the author was unable to determine the identity of the key local pollinators and dispersers. Offsetting this deficiency is one of the key roles for the biologist member of the restoration team during the development of the detailed site restoration prescription. On the basis of the available information it is recommended that, at a minimum, a set of bird perches should be installed in the short term to encourage visits to the site by seed dispersers. These should be approximately 2 m tall and installed within the proposed forest portions of the property until the seedlings grow to a sufficient height to take over the refuge function of the perches. Ants are also important dispersers and, over the longer-term, their colonisation of the site should be encouraged when soil conditions become favourable to their life requirements.

Pollination is another vital plant-animal mutualism that must be restored to the site. One way to achieve this is by introducing honeybees to the site by arranging with a local beekeeper to maintain their hives on site during the flowering season. While this may not address the pollination needs of all species colonising the site, it will provide an important first step. The use of honeybees can have the addition benefit creating educational opportunities for local school children. Other wild species of pollinators can be introduced to the site as they are identified.

Maintenance:

One of the main maintenance tasks will be the addition of appropriate levels of fertiliser to the site as a stopgap measure until full nutrient cycling can be achieved onsite. As part of this process soil fertility must be closely monitored to ensure over fertilisation does not occur. Fertiliser application on the meadow landscape should be limited to the initial establishment period in order to ensure that the restoration results in the desired low fertility, species rich community.

The second main maintenance activity will be weed control. As mentioned previously heavy applications of mulch can be used initially for weed control in the forest areas until the seedlings reach the free-to-grow stage. From this point hand removal of weeds using mechanical or chemical means is recommended to remove only noxious weeds and unwanted tree species. For the meadow landscape mowing is recommended as a weed control until the desired herbs species reach 6 inches high. Once the plants reach this level of development weed removal should follow the methods proposed for the free-to-grow forest landscape.

This recommendation is only a general framework for furthering the plans for the restoration of the land at the mouth of the Current River. It roughly outlines the recommended soil treatment, facilities to be constructed, and the principles for revegetation, plant and animal mutualism restoration, and maintenance. Further work will be required by the City of Thunder Bay and its staff and consultants to develop a detailed restoration prescription for the site.

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APPENDIX A: SPECIES SAMPLED

The following plant species were located in the sample plots collected from the Current River site in October of 1996.

<u>Herbs</u>:

Species Name	**Common Name**
Solidago canadensis L.	Canadian Goldenrod
Plantago major L.	Common plantain
Aster ciliolatus Lindl.	Ciliolate aster
Fragaria virginiana Dcne.	Common strawberry
Equisetum pratense Ehrh.	Meadow horsetail
Epilobium angustifolium L.	fireweed
Callicladium haldanianum (Grev.) Crum	callicladium moss
Linaria vulgaris Miller	Butter and eggs toad flax
Anaphalis margaritacea (L.) C.B. Clarke	Pearly everlasting
Dicranum sp.	Dicranum moss
Trifolium pratense L.	Red clover
Vicia americana Muhl.	American vetch
Taraxacum officinale Weber	Dandelion
Achillea millefolium L.	Yarrow

Hydrocotyl americana L.	Water pennywort
Sisyumbrium altissiumum L.	Tumble mustard
Urtica dioica L.	Stinging nettle
Sonchus arvensis L.	Corn sow-thistle
Typha latifolia L.	Cat-tail
Cirsium muticum Michx.	Swamp thistle

Shrubs:

Species Name	**Common Name**
Alnus viridis ssp. crispa (DuRoi) RT Klassen	Green alder
Alnus incana ssp. rugosa (Aiton) Turrill	Speckled alder
Amelanchier sp.	Service berry
Cornus stolonifera Michx.	Red osier dogwood
Corylus cornuta Marsh.	Beaked hazelnut
Carryagana Sp.	Siberian peashrub
Salix sp.	Willow
Sambucus canadensis L.	Canada elderberry
Rosa blanda Ait.	Smooth wild rose
Rubus ideas L. ssp. *melanolasius* Focke	Wild red raspberry

Trees:

Species Name	**Common Name**
Abies balsamea Mill.	Balsam fir
Acer rubrum L.	Red maple
Betula papyrifera Marsh.	Paper birch
Fraxinus nigra Marsh.	Black ash
Populus deltoides Marsh.	Eastern cottonwood
Populus balsamifera L.	Balsam poplar

Please not that the above list is not a complete enumeration of the various species of plants located on the Current River property. A number of species observed on site during site reconnaissance and traverses of the site which were not found in any of the sample plots are: American mountain ash (*Sorbus americana* Marsh.), jack pine (*Pinus banksiana* Lamb.), eastern white cedar (*Thuja occidentalis* L.), white spruce (*Picea glauca* (Moench) Voss), American elm *(Ulmus americana* Mill.), and a number of unidentified varieties of ornamental crab apples (Malus sp.).

APPENDIX B: MAP OF SAMPLE PLOTS

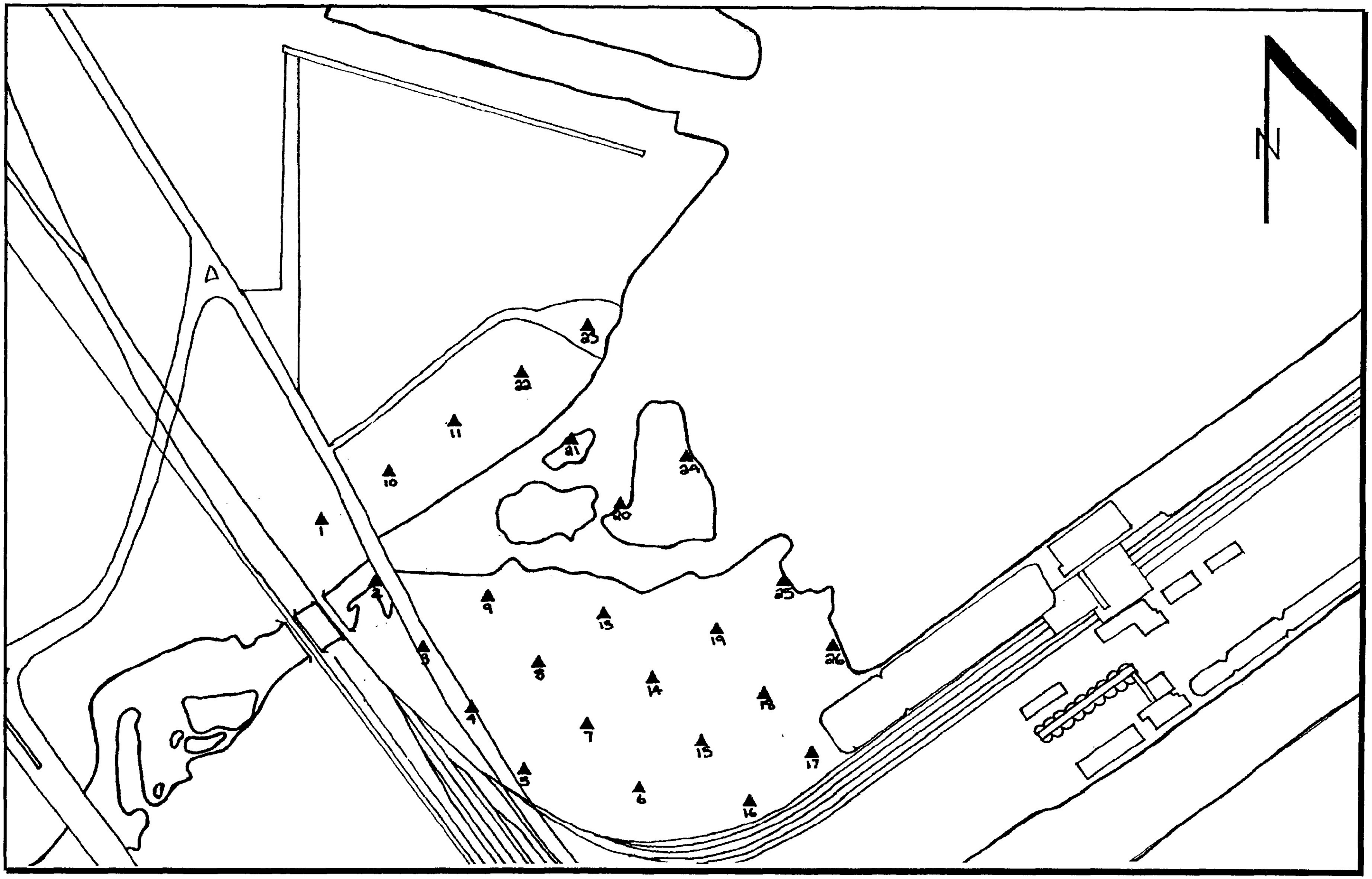

Figure 25: Map of Current River Sample Plots.