BROWNFIELD REMEDIATION: SOLUTIONS FOR URBAN AGRICULTURE

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Executive Summary

Urban agriculture is an important emerging field because of its positive implications for urban food security, community development, and urban environmental conditions. However, community groups pursuing urban agriculture face many obstacles. Soil contamination is a major barrier to potential agriculture projects in urban areas, as most urban soil is below agricultural soil standards, and food cannot be grown in contaminated soil because of the associated human health risks. Unused, contaminated lands in urban areas known as 'brownfields' have great potential as sites for urban agriculture if remediation can be successfully undertaken. Though many soil remediation techniques exist, they are of varying practicality for community groups attempting the remediation of brownfields for urban agriculture.

The goal of this project is to evaluate several physical and biological soil remediation techniques for use by community groups using the following criteria: accessibility, cost, time, ability to bring soil up to agricultural standards, and environmental effects. Our specific research questions were as follows: What are the initial steps a community group should follow before beginning a remediation project? What are the various soil remediation techniques that can be used to achieve these soil quality requirements? What are the pros and cons of available remediation techniques for use by community groups for the purpose of urban agriculture? What can we learn from case studies of past remediation attempts undertaken by community groups for this purpose? To determine the answers to these research questions, the research team consulted academic journals, sources from the Quebec, Canadian, and US government, and conducted interviews with academics, Montreal city officials, representatives from remediation companies, and community group members.

It was determined that although soil standards exist at several levels of government, community groups should follow the most stringent ones, as they are liable for any contamination of the food

produced in their gardens. The research team also explored resources available for determining the land use history of a proposed garden plot and for soil testing, which will enable a community group to determine the levels of contamination present in the soil. Sources of subsidies were also explored, with results from the Revi-Sols program in Quebec, and the Brownfields Partnership Action Agenda program in the United States.

Four physical remediation methods were evaluated: excavation, geotextiles, soil washing and soil vapor extraction. Of these methods, excavation was determined to be the most appropriate option for community groups, as it can ensure complete contaminant removal in a very short time frame. Other techniques were deemed too technical and costly for use by community groups, and had negative environmental consequences. Of the biological remediation techniques (microbial remediation, phytoremediation, fungal remediation, and composting), microbial remediation was selected as most effective for community groups, as it has very low associated costs and can be effective in a relatively short timeframe. Other techniques were less accessible, took longer to implement, and had varying degrees of effectiveness in bringing soil up to agricultural standards. It should be noted that these are only general conclusions; selection of a remediation technique must be done on a case-specific basis, since variance in the level and spectrum of contaminants in the soil, the soil's properties, and the available timeframe and budget will all determine the appropriateness of each technique for the urban agriculture project.

Finally, the research team recognizes that the field of soil remediation for urban agriculture is quite young, and some techniques that are not presently applicable may have a promising future.

Sommaire exécutif

L'agriculture urbaine possède des implications positives, car celle-ci assure une nutrition sécuritaire dans les villes, un développement communautaire, et des avantages environnementaux dans un milieu urbain. Cependant, les groupes communautaires qui poursuivent l’agriculture urbaine doivent faire face à beaucoup d'obstacles. Un des plus importants est la contamination des sols qui empêche des projets d'agriculture de se développer dans des secteurs urbains. Ceci s’explique par le fait que la plupart des terrains urbains possèdent des niveaux de contamination au dessus des normes agricoles. Donc, la nourriture ne peut pas être cultivée dans ces sols parce que c’est trop dangereux pour la santé humaine. Des terres inutilisées et contaminées offrent des possibilités intéressantes pour l'agriculture urbaine, seulement si la restauration peut se faire avec succès. Bien que beaucoup de techniques de réhabilitation de sols existent, elles ne sont pas toujours utiles pour des groupes communautaires qui souhaitent développer l'agriculture urbaine.

Le but de ce projet est d'évaluer plusieurs techniques physiques et biologiques de réhabilitation de sols qui pourraient être utilisées par des groupes communautaires. Nous avons choisi les critères suivants pour tester si une certaine méthode peut être efficace: l’accessibilité, le coût, le temps, l’habileté de réduire les polluants jusqu'aux niveaux agricoles, et les conséquences environnementales de chaque technique. Nos questions de recherches sont les suivantes: Quelles sont les étapes initiales que doivent poursuivre des groupes communautaires avant de commencer la réhabilitation des sols? Quelles sont les techniques qui existent à propos de la restauration des sites contaminés? Quels sont les avantages et les désavantages de ces techniques pour les groupes communautaires pratiquant l'agriculture urbaine? Que peut-on conclure en étudiant des projets de réhabilitation qui ont été déjà développés par des organisations communautaires pour l’agriculture? Pour déterminer les réponses à ces questions, notre équipe de recherche a consulté des journaux

scolaires, et des documents gouvernementaux du Québec, du Canada, et des États-Unis. Nous avons aussi interviewé des fonctionnaires académiques, des représentants de la ville de Montréal, des membre de compagnies de restauration, et de groupes communautaires.

Nous avons déterminé que les normes à poursuivre pour cultiver dans des sols urbains existent à plusieurs paliers de gouvernement, dont le provincial et le fédéral. Les groupes communautaires devraient faire référence aux plus rigoureux, car ils sont responsables de la contamination présente dans la nourriture, cultivée dans leurs jardins. Nous avons aussi recherché des ressources pour vérifier les utilisations passées et les polluants d'un certain terrain. De plus, il existe des subventions, par exemple Revi-Sols au Québec, et le programme « Brownfields Partnership Action Agenda » aux États-Unis, qui pourront être utiles pour les organisations qui souhaitent développer un jardin communautaire.

À propos, de la réhabilitation des sols, quatre méthodes physiques ont été évaluées: l'excavation, les géotextiles, le lavage de sol et l'extraction des vapeurs du sol. De ces méthodes, l'excavation a été déterminée la meilleure option utile pour des groupes communautaires, parce qu'elle assure l'absence complète de polluants en très peu de temps. Les autres méthodes ont été considérées trop techniques et coûteuses pour être utilisées par des groupes communautaires et de plus, causaient des effets néfastes sur l'environnement. À propos des techniques de restauration biologiques (réhabilitation microbienne, phytoréhabilitation, la réhabilitation fongique, et le compost), la réhabilitation microbienne a été choisie comme étant la plus efficace pour des groupes communautaires, car celle-ci n'est pas très coûteuse et possède le potentiel de réduire les niveaux de contamination respectifs aux normes agricoles dans une période de temps relativement courte. D'autres techniques étaient moins accessibles, prenaient plus de temps par décontaminer le sol, et leur degré d'efficacité à réduire les niveaux de contamination aux normes agricoles variait. Il est important de noter que ces conclusions sont générales et chaque cas de terrain contaminé est spécifique. Le choix de la méthode de réhabilitation utilisée doit être basé sur le niveau et le type des polluants présent dans le sol, ainsi que sur les propriétés de celui-ci. De plus, des organisations communautaires doivent choisir une technique qui leur sera convenable en termes de coût et du temps qu'il faudra pour décontaminer le sol jusqu'aux niveaux agricoles.

En conclusion, la recherche sur les techniques de réhabilitation des sols urbains contaminés ayant pour but l'agriculture commence à se développer, et les techniques qui ne sont pas très efficace aujourd'hui pourront probablement être perfectionnées dans l'avenir.

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Introduction

Urban agriculture is becoming more important in today's cities. It has great potential to improve the quality of life in urban areas by increasing food security, providing opportunities for community development, and improving the aesthetics of the urban landscape. Community organizations practicing urban agriculture face many obstacles, such as land availability, restricted budgets and soil contamination. Soil contamination is a major barrier to urban agriculture initiatives, because contaminants are present in most urban soils at levels higher than are accepted for agricultural use. These contaminants can be taken up by plants grown in these soils, and can be harmful to human health if the produce is consumed. The barrier of land availability could be partially overcome if brownfields could be used as sites for urban agriculture. Brownfields are unused plots of urban land that are contaminated from previous land uses. If these brownfields could be remediated by community groups, they would further the development of urban agriculture projects. Remediation involves the removal of contaminants, in this case such that the soil meets conditions for urban agriculture.

This project is concerned with the viability of brownfield remediation for urban agriculture. It explores the applicability of various remediation techniques to community groups practicing urban agriculture. It describes agricultural soil standards, resources available for determining the land use history of a plot of land and for soil testing (to determine the level of contamination in the soil), several physical and biological remediation techniques, and the pros and cons of these soil remediation techniques from the perspective of community groups. Techniques that were analyzed include excavation, geotextiles, soil washing, soil vapor extraction, microbial remediation, phytoremediation, fungal remediation, and composting.

This research was accomplished by consulting available literature, government sources, internet resources, and through interviews with academics, city officials, representatives of remediation companies, and members of community groups, who provided us with case studies of remediation for urban agriculture. Our research was limited by the relative youth of the field of soil remediation. In particular, biological remediation techniques are only recently coming into use, and some are still in the developmental stages. As for the evaluation and recommendations of the most appropriate techniques, only very general conclusions can be reached. The specifics of an urban agriculture project will ultimately determine which technique(s) should be used. Variation in contamination, soil type and characteristics, time and funds allotted for remediation will all influence which technique a group should pursue.

Context / Literature Review

Urban Agriculture: History and Benefits

The history of urban agriculture in North America dates back to the Great Depression. During this time, the Work Projects Administration in the United States provided city land for gardens to the unemployed and impoverished (Armstrong 2000). Later, during World War II, the Victory Gardens Program was initiated to provide fresh vegetables and led to the creation of an estimated 20 million gardens ac(Murphy 1991, p.1).

The importance of urban agriculture today is based primarily on its ability to increase urban food security. Hunger and malnutrition have been rising in industrial societies, bringing the purported success of modern farming methods into question (Koc and Dahlberg 1999; Riches 1997). As our increasingly globalized food system is largely unresponsive to individual and community needs, a logical way to address these needs would be at the local level in the form of urban agriculture.

Environmental benefits are also central to the importance of urban agriculture. Decreased fossil fuel emissions are a major benefit, since it renders transporting and refrigerating food over long distances unnecessary. Urban agriculture also reduces packaging, mitigates storm-water runoff, increases oxygen production, and controls temperatures through increased shade and transpiration (Lawrence 1996,). Other noted environmental benefits include the contained cycling of organic wastes within the urban environment (Nelson 1996), and increased biodiversity, as the gardens can provide new habitats for the biota of the urban area (Fairholm 1998). Efforts to green cities through urban agriculture also enhance environmental stewardship in the present and foster environmental awareness for the future.

There is a substantial and growing pool of information available on the practice of urban agriculture. This literature is produced primarily by three sources. Community groups themselves (Eco-Initiatives 2002; Foodshare 2002; Hillcrest Community Center 2002) promote their gardening initiatives and provide resources for garden establishment. Electronic databases and community groups compile information from a variety of sources (City Farmer 2002; Resource Center on Urban Agriculture 2002) making this knowledge available to the public. Lastly, a great deal of the literature has been written by academics studying benefits, costs and feasibility of urban agriculture. Lawson (1995) discusses how community gardening can facilitate community development, while Brown (2000) and Brown and Jameton (2002) show that urban agriculture is beneficial for food security and public health. In addition, Armstrong (2000) advocates the psychological and health benefits drawn from gardening.

Barriers to Urban Agriculture

Along with the multitude of benefits of urban agriculture come a multitude of barriers to its successful implementation, especially by community groups with limited resources. In most cases the problem is not the availability of land – one study estimated the cultivable land in Vancouver at 6500 acres (Levenston 1995) - but rather issues of feasibility that will determine the success and sustainability of urban agriculture in the future. Issues such as property rights, restrictive urban planning, access to funding and soil contamination remain significant impediments to garden development (Fairholm 1998). This section reviews some of the main impediments to the establishment of urban agriculture.

There can be many practical barriers to urban agriculture. These may include a lack of technical knowledge, lack of access to land or markets (for those interested in selling their produce), or high start-up costs which exclude low-income individuals or community groups operating on strict budgets. Until recently, governments had developed few policies to overcome these barriers. Reasons for this unresponsiveness from governments include a lack of awareness of the socio-economic and environmental benefits of urban agriculture, lack of clear government responsibility, recalcitrant attitudes or cultural norms of parties in the land use planning process, and a lack of resources, technical and financial support (Mougeot 1999). In many cases, however, community organizations for urban agriculture have been created at the municipal level. Both the City of Montreal and the City of Toronto have departments dedicated to the development and support of urban agriculture. However, in general the lack of policy development surrounding urban agriculture remains a barrier to implementation.

Contamination in urban soils presents a major challenge to urban agriculture, as it does for any form of sustainable land use solution (Nijkamp 2002). Previous land use may have contaminated soil to the point that it is unsuitable for agricultural, residential, commercial or industrial use. These contaminated lands (‘brownfields’) present a particular problem for urban agriculture because the produce grown in such soil has a risk of contaminant uptake, which may pose a health risk when consumed by humans. However, identifying the contaminants and assessing the level of contamination can be difficult, as there may be little or no information available. In light of these problems, it is useful to provide a brief general background to brownfields, and the issues surrounding them.

Introduction to Brownfields

The definition of brownfields as used by the United States Environmental Protection Agency (EPA), is “abandoned, idled or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination" (EPA 2002, p. 1). At present there are approximately 3000 brownfield sites across Canada (NRTEE and CMHC 1997, p. 11-12) and an estimated 132,000-176,000 in the United States (Wright 1997, p. 5). Some examples of industries that may leave the land contaminated include coal distillation plants, the petro-chemical industry, electronic equipment manufacturers, as well as businesses like dry cleaning and photo processing.

The remediation of these contaminated lands has many associated benefits. These benefits range from addressing concerns of human and ecosystem health, to economic and political benefits. Given the risk posed to human health by toxic levels of contaminants, primary benefits of remediation are the elimination of a source of contamination, and the prevention of the spread of contaminants present in the brownfield to nearby areas through atmospheric and water transports (Wright 1997, p. 4). As well as being a human health concern in these areas, land contamination poses a threat to the health of the surrounding environment and the plants and animals therein. Another environmental benefit of the remediation and redevelopment of contaminated land is its role in the preservation of uncontaminated 'greenfield' land, particularly at the urban periphery.

The remediation of a contaminated site clearly makes sense for health and environmental reasons. The benefits of remediation become more economically tangible once the land is put back into productive use (Kibert 1999, p. 296). These include (but are not limited to) increased tax revenue, creation of jobs in that area, and limiting the need for urban sprawl. Another benefit that developers and the municipality can reap from redeveloping brownfields is the ability to use city infrastructure already in place. When infrastructure is taken into account, it is often more cost effective to clean up and use a site that already has municipal services present, such as sewer, water utilities and transportation, than to extend those services to previously undeveloped greenfield sites (NRTEE and CCME 1997, p. 30).

Despite these benefits, the redevelopment of contaminated land was not addressed by governments until the 1990s, when policy incentives for remediation began to emerge (Kibert 1999, p. 296). Before this time, those seeking to develop land may have been inclined to choose untouched greenfield sites rather than taking on a brownfield site due to high clean-up costs, lengthy time delays, and possible legal problems and regulatory burdens (Wright 1997, p. 6). As environmental consciousness and the need for alternatives to new land development have grown, so have government policy incentives to developers. These incentives help to offset the remediation costs and liability issues that have previously made brownfield redevelopment unattractive to developers and the capital which finances them. These policy incentives may include remediation tax credits and subsidies, voluntary clean-up programs, and other forms of assistance from all levels of government.

The literature on brownfields is widely available in peer-reviewed sources, government publications, and in the media. The information provided there focuses on the remediation of large-scale, highly contaminated sites, redevelopment in the context of real estate and city planning concerns, and policies which enable these problems to be dealt with more effectively. In light of this, we need to better define the place of urban agriculture in the context of brownfield remediation.

Brownfield Remediation for Urban Agriculture

As we have outlined in the preceding sections, soil contamination can be a significant barrier to urban agriculture and many other forms of urban land use. While there is substantial literature on remediating large, highly-contaminated sites, there is less material on the remediation of small, lesser contaminated sites, such as those that might be considered for urban agriculture.

The current information available on brownfields provides some possible reasons for the exclusion of smaller sites. The focus on brownfield remediation has almost exclusively stressed the context of city planning and real estate redevelopment, and the policy development has proceeded accordingly. One major issue here is the cost of remediating these sites, which can be prohibitively expensive without accompanying financial support, and/or prospects for seeing a return on the investment (Simons 1998).

These economic realities provide a background for the issue of brownfield remediation for urban agriculture. Where does a land-use that is essentially non-economic fit into an economic framework? In light of the fact that, per unit area, urban agriculture may generate minimal revenues – or more often none at all – what options are available for the remediation of contaminated potential agriculture sites?

In order to further address the problem of brownfield remediation for urban agriculture, further information is required. Remediation inevitably raises the problem of soil contamination, and the viability of the various available remediation techniques. In the next two sections, the issues relating to soil contamination and remediation techniques are introduced. In the Analysis section of this report, they will be discussed in much greater detail.

Soil Contamination

As stated above, soil contamination is a major barrier to urban agriculture. The health risks associated with the human ingestion of produce grown in contaminated soils are a primary concern. In particular, knowledge about the range and nature of contaminants in soil and the acceptable levels of contamination is essential in shaping the remediation decision-making process.

The range and nature of soil contaminants is the subject of a wide range of literature, including peer-reviewed journals, books, and government publications. With regard to the acceptable levels of contamination for agricultural use of the soil, government classifications are established at the provincial and federal level. The assessment of soil contamination will be discussed at length in the Analysis section of this report.

Remediation Techniques

One important aspect of any a soil remediation project is the selection of a remediation technique. There are a wide range of options available, ranging from physical excavation and disposal of the contaminated soil to the treatment of the soil with contaminant-extracting vegetation. Each option has positive and negative features which must be taken into account when selecting the most appropriate technique.

Physical techniques are one category of soil remediation techniques. These include excavation, using geotextiles as a contaminant barrier, soil washing, and soil vapor extraction. The literature on these techniques is generally highly technical. The focus of studies is often narrow in scope; it is more common to find research on the effectiveness of one technique in removing one contaminant (Poland *et al.*, 2001) than to find broad surveys of techniques (Rivett *et al.*, 2002). Studies of physical techniques are often carried out in laboratory situations, such as by Wasay (2001). Only occasional case studies or experimentation are done in situ. In general, the literature on physical techniques often neglects issues of cost or practical implementation. The literature is lacking in non-industrial and agricultural applications of these techniques.

As for microbial remediation, extensive research has been done on the use of micro-organisms to break down chemical contaminants into forms that are less toxic. While many studies have shown the effectiveness of microbial biodegradation, most have focused on a specific chemical process or single contaminant, using a specific bacteria (Pollard *et al*. 1994; Caldwell *et al*. 1999; Bruins *et al*. 2000; Puzon *et al*. 2002). Conclusions from these studies are often irrelevant to practical remediation projects, as most urban soils are contaminated by a variety of pollutants. Nevertheless, the background information provided by many of these studies on the contaminants, soil conditions, and successful methods of stimulating the microbial decomposition of contaminants (Norris *et al.* 1993; Young and Cerniglia 1995; King *et al.* 1998) has proved to be very useful in informing our overall research.

Phytoremediation is the use of plants to extract, sequester and/or detoxify heavy metals and organic contaminants. This is a budding new field of research that shows much promise – particularly because it may be the only effective means of restoring large areas of contaminated land (Meagher 2000). Phytoremediation is relatively cost-effective (Bollag *et al*. 1994); estimates of phytoremediation average around $80 per cubic yard (Black 1995). Apart from its affordability, phytoremediation could also be recommended to community groups because it is a natural, aesthetically pleasing, low-cost technology (Pradhan *et al.* 1998, Ensley 1997) and may also offer immediate and long-term environmental benefits.

Most research on phytoremediation has focused on phytoextraction, a process where plant roots absorb heavy metals from the soil. Some environmentally important toxic metals such as lead, cadmium and arsenic have a limited bioavailability to plants and are not absorbed very well. The discovery of chelating agents, which when applied to soil can induce plants to accumulate higher concentrations of these metals, has sparked much interest within the scientific community

(Blaylock *et al.* 1997). While this induced phytoextraction method is the most developed of the plant-based remediation techniques (Salt *et al.* 1998), it is unsuitable for urban gardening because the chelating agents which speed up the extraction process can also contaminate the soil if not properly used.

Some literature has been published on the benefits of composting for degrading contaminants at industrial sites and army bases (Riggle 1995; Laine and Jorgenstein 1997; Bruns-Nagel *et al.* 1998). Case studies have been conducted on projects that used composting to biodegrade organic contaminants through accelerating microbial activity in ideal conditions (Abiola and Olenyk, 2000; Goldstein, 2000).

Fungal remediation techniques are another research area that is receiving academic attention. White rot fungi have been studied primarily for their potential ability to degrade lignin, as well as a diverse group of environmental pollutants (Reddy and Mathew 2001, p. 52). However, these studies were conducted in ideal laboratory conditions. Field studies did not prove to be as successful in degrading contaminants. Hence the applicability of such techniques for urban agriculture is unclear, and will be discussed in greater detail in the Analysis section of the report. At present very little is known about the remediation of small-scale urban plots. In addition, there is a serious lack of information on whether phytoremediation practices can render land safe for agricultural use.

Conclusion

Researching the topics of urban agriculture, brownfields, and soil remediation has shed light on the many gaps in the literature. There is a limited amount of literature on brownfield remediation and soil contamination in the context of urban agriculture. Little research has been done on general urban soil contamination on the small scale of urban plots. Most of the scientific literature focuses on large-scale, industrial contamination and remediation. Studies often have narrow focuses and are too specific. The potential for remediation of multiple contaminants is often not addressed.

Furthermore, little research has been done on the potential for remediation techniques to bring soil up to agricultural standards. This knowledge is imperative for urban agriculture. The cost issues and the practicality of implementation for community groups' budgets and resources are also neglected in the literature.

Our research addresses these neglected areas of study, with the aim of providing a comprehensive guide for community groups seeking suitable soil remediation techniques to further their pursuit of urban agriculture. Our research aims to provide general information on urban soil contamination and methods for dealing with small-scale polluted sites. After surveying the literature available, it is clear that determining the feasibility of urban garden development on contaminated soil must rely more heavily on personal interaction with experts for particular aspects of this area of inquiry rather than on the literature.

Research Questions

The research team defined the following specific research questions to clarify the project objectives:

1. What are the initial steps a community group should follow before beginning a remediation project?

2. What are the various soil remediation techniques that can be used to achieve these soil quality requirements?

3. What are the pros and cons of available remediation techniques for use by community groups for the purpose of urban agriculture?

4. What can we learn from case studies of past remediation attempts undertaken by community groups for this purpose?

Methodology

In order to answer the research questions, the research team utilized the following methodology. In general, the team reviewed the available literature, conducted web research, and consulted with academics, representatives of remediation companies, and community groups. To answer the first research question, we decided that we needed to find information on soil quality standards, resources for determining land use history, associations of land use with soil contamination, soil testing, and financial resources for remediation. Beginning with soil quality standards, we searched the web sites of the Canadian Council of the Ministers of the Environment as well as Environnement Quebec to find the acceptable levels of contamination for agricultural lands. We later consulted with experts to determine which standards should be followed when there are different acceptable amounts of contamination at the federal and provincial level. Next we looked into the problem of how to find out land use history for a given plot of land. Through internet research, we found that the EPA had resources on the association of certain types of land use with specific types of soil and groundwater contamination. We found information on soil testing on the Canadian Gardening web site. For information on subsidies for remediation, we consulted the EPA web site for resources in the United States, and conducted an interview on November 14, 2002 with Serge Barbeau, General Director of the Centre D'Excellence de Montréal en Réhabilitation de Sites (CEMRS) to find resources available in the city of Montreal.

To answer research question 2, the team took a list of techniques provided by Eco-Initiatives, the client for this research project, and for each technique conducted a review of available literature in books and academic journals. In cases where this method did not provide a complete definition of the technique, the way it worked, or its capabilities, web resources (primarily web sites of soil remediation companies) were consulted.

To answer research question 3, we created an analytic framework with which to evaluate the chosen remediation methods. We determined that the most important criteria in the selection of a remediation technique from a community group's perspective were accessibility, cost, timeframe, effectiveness for urban agriculture and environmental effects. These criteria are discussed in detail in the analysis section. To evaluate how each technique performed relative to these criteria, we first researched the literature. Such literature only provided information on some of the criteria, so we created a questionnaire for academics, remediation experts and community groups. This questionnaire was administered by e-mail, over the phone or in person, and can be found in Appendix A. The questionnaire was administered to Professor Gerda Wekerle at York University, Professor Subhassis Ghoshal at McGill University, Professor William Hendershot at McGill University, Mr. Charles Greer from the NRC Biotechnology Research Institute, Laura Berman from Foodshare, Kristin Brennan from The Food Project and Serge Barbeau, general director of the CEMRS. For the cost of certain techniques, remediation companies were consulted by interview, including Mr. Mario Notargiacomo at Canada Excavation, Mr. David Neubauer at Geochem Inc., Dr. Carl Oppenheimer at Oppenheimer Biotechnology Inc., President Jay Murland of Envirologic Inc., President Guy McGowen of the Capano Institute, Mr. Richard Malot at Terravac, and Mr. Larry Wood at Terra Resources Ltd (See Appendix A, for Questionnaire and List of People Interviewed).

Finally, to answer research question 4, we conducted internet searches looking for community groups that had successfully remediated sites for urban agriculture. We also included a question on the interview questionnaire asking the interviewee to refer us to any successful soil remediation projects they had heard of. After looking into the work of many community groups, we found two groups that had successfully remediated land for agriculture (The Food Project in Boston and Eco-Initiatives in Montreal), we sent them the section of the questionnaire designated for community groups, and followed this up with interviews. Some of the information obtained from the case studies was applied to the evaluation of the remediation techniques suitability for community groups.

Analysis

Soil Standards

Soil quality standards for agriculture may vary between the federal and provincial/state level. Community groups are advised to take a precautionary approach and follow the most stringent standards for each contaminant. Soil standards for Canada and Quebec can be found in Appendix B.

Land Use History

Certain land use histories are associated with specific types of soil contamination. For community groups operating on a restricted budget, determining previous land use can help to narrow the range of contaminants in a given plot that must be tested for and therefore reduce soil testing costs.

The first step in determining previous land use is to find out the lot number of the piece of land in question. This information is available at the City Hall of any town. Once this has been accomplished, the next step is to determine previous landowners and their land uses. Depending on how far back a group wants to research ownership, there are a variety of resources that can be helpful. Resources specific to Montreal are listed in Appendix C, and it should be noted that similar resources are generally available in most cities.

A table from the US Environmental Protection Agency that indicates which contaminants may be found on certain sites as a result of previous land use can be found in Appendix D. This is a valuable resource to community groups to help them evaluate which contaminants should be tested for.

Soil Testing

Determining land use history should give community groups an idea of the potential contaminants in their plot. They can therefore narrow the range of contaminants they choose to test for. This is important for practical reasons because soil testing can range from $10 per sample to $850 per sample depending on how comprehensive the test is. Guelph University has an arrangement with Foodshare and the Toronto Community Garden Network and provides comprehensive soil testing for about $90 per sample. University laboratories can often provide affordable testing services to community groups, but it is important to determine whether or not the laboratory is certified. In order to comply with soil contamination regulations, only test results from certified labs can be accepted. Some soil testing resources are listed by province in Appendix D.

Subsidies

The decision to undertake a remediation project will be less daunting if financial resources can be secured to defer the costs. The main financial assistance program developed by Quebec's Ministry of Environment is called Révi-Sols. Its goal is to encourage landowners and developers to remediate contaminated sites that have the potential for economic development. Révi-Sols started in 1998, and is slated to run for 5 years. The government of Quebec will provide financial assistance of $10M for site remediation in Quebec city, $30M in Montreal, and an additional $50M for all the other municipalities in the province (Environnement Quebec 2002).

Any property is eligible regardless of the nature or the source of contamination. Remediation projects on municipal lands as well as on private lands can obtain assistance. The rehabilitation process must include characterization of the plot, risk assessment, the identification of rehabilitation techniques (in situ, ex situ, soil excavation), preparations of plans and specifications, rehabilitation, work supervision, drafting of a final report, and environmental monitoring for the duration of the project (Environnement Québec 2002). Through Révi-Sols, the government pays 50% of the total cost if the soil is removed, and in some cases it will cover 70% of the cost if soil treatment is performed (Barbeau, 2002). Contributions are distributed through direct grants, debt service subsidies, and debt service equivalent.

Brownfields Federal Partnership Action Agenda

The US Environmental Protection Agency has committed up to $850 million over the next five years to states, tribes, counties, municipalities, and non-profit organizations for Brownfields assessment, clean-up, revolving loan funds, job training and state/tribal grants.

Other commitments include resolutions by the U.S. Economic Development Administration, the U.S. Department of Housing and Urban Development, the U.S. Department of the Interior, the U.S. Department of Justice, and the U.S. Department of Labor to offer funding priority to Brownfields communities through their respective grant mechanisms (US Environmental Protection Agency, 2002).

Remediation techniques

Physical methods

There are many different kinds of physical remediation techniques, ranging from the relatively basic, such as excavation, to the highly complicated and technical. We have profiled here several widely used techniques of varying complexity. A great deal of research and development is currently being done in this field, and thus this section should not be considered an exhaustive listing of available technology. It is mainly intended to highlight some techniques that would be applicable to small-scale urban agriculture, while illustrating the wide range of physical techniques available.

Excavation

Excavation involves physically removing contaminated soil from a site for disposal or recycling. Generally, contaminated soils are removed with heavy equipment and loaded onto trucks that carry the soil to a licensed landfill. The fate of the removed soil depends on the extent of contamination, and the amount of soil excavated. Soil contaminated with hazardous materials requires special treatment, and large amounts of soil cannot be disposed of in a landfill, so further remediation is necessary (T.M. Gates Inc. 2002).

Geotextiles

Geotextiles are made from synthetic fibers, generally polypropylene or polyethylene, which are bound together to form a blanket-like material. There are two types of geotextiles, woven and non-woven (Neubauer 2002). These terms refer to the process by which they are manufactured. Geotextiles have many uses, but in the context of agriculture, non-woven geotextiles are used as a barrier in the soil to control the migration of contaminants, and are used in conjunction with excavation (Steinberg 1998,). After contaminated soil has been removed, geotextiles can be used to line the excavated area before new soil is brought in. This will prevent the migration of contaminants from the area into the new soil.

Soil Washing

Soil washing uses chemical and physical processes to extract and separate contaminated materials in soil. It is used *ex situ* to remove organic, inorganic and radioactive forms of contamination. It is normally not sufficient to completely decontaminate the soil, and is therefore generally used as a pre-treatment (Anderson 1993).

Soil is first excavated and oversize materials are removed. It is then washed with water or another cleaning agent, depending on the contaminants present. The presence of different types of contaminants may require multiple washes with different solutions. The washing process concentrates the contaminant in one part of the soil, leaving the rest free of the contaminant. Soil washing is most effective on soils with high sand and gravel content, and is less effective on soils with high silt and clay content (Anderson 1993). It can remediate soil contaminated with petroleum or fuel, radionuclides, heavy metals, PCBs, PCP, pesticides, cyanides, creosote, as well as some semivolatile and volatile compounds (Terra Resources Ltd. 2002).

Soil Vapor Extraction

Soil vapor extraction (SVE) removes contaminants from the soil in vapor form. The process involves applying a vacuum through a system of underground wells and piping. The contaminants are then brought to the surface as a gas. Air injection wells can be installed to increase airflow, which speeds removal of the contaminants. There are two types of soil vapor extraction, vertical and horizontal. Vertical SVE lines are used in the case of deep contamination, while horizontal SVE lines are used in cases with shallow contamination. SVE can remove volatile organic compounds such as trichloroethenes, trichloroethanes, benzene, toluene, ethylbenzene, xylenes, some semi-volatiles, and fuels located beneath the ground surface in the unsaturated zone (the area of the subsurface above the water table). Once these contaminants are removed, the vapors still require treatment, but treating the vapors is less costly than treating soil. SVE works best on soils types like sand, gravel, coarse silt or fractured bedrock. It is can be effective on other types of soil, but these will require longer treatment periods. SVE is most effective on soils with low moisture content (Sojourn Environmental Company 2002).

Biological methods

Microbial Remediation

Microbial remediation utilizes microorganisms to degrade soil contaminants into a less toxic form. The three main techniques of microbial remediation are natural attenuation, biostimulation and bioaugmentation. Natural attenuation is a passive method of remediation in which the soil is left alone and the bacteria in the soil break down the contaminants without any outside help or encouragement. Biostimulation involves encouraging the growth of the naturally occurring bacterial species in the soil. Bioaugmentation is the process of introducing into the contaminated site species of bacteria not naturally present in that location.

The natural microbial process in the soil will break down most of the common soil contaminants. The ease with which the microbes can break down the contaminants depends on the chemical structure of the pollutants. Contaminants such as BTEX compounds and most petroleum hydrocarbons are very easily biodegraded. More complex petroleum hydrocarbons, such as PAHs, pesticides (such as DDT and other compounds), PCBs, PCE (tetrachloroethene) and TCE (trichloroethene) are slightly more difficult to degrade, but can still be biodegraded fairly easily. Metals are the most difficult contaminant for microbes to degrade (Oppenheimer Biotechnology, Inc. 2002), because under certain circumstances it is possible for the change in the ionic state of the metal to cause the compound to become even more toxic.

The most common method of bioremediation is biostimulation (King 1998, p. 7). This technique involves adjusting the environment to conditions which promote and attempt to maximize the activity of the bacterial species that will break down the contaminants in the soil. The ways in which the soil can be made more favorable to microbial activity include adjusting the pH, temperature, moisture, nutrient content and oxygen levels to the levels in which the bacteria are most productive.

Standards for the optimal activity of biodegrading microorganisms have been derived from a fundamental understanding of microbial processes and experimentation in the lab. The ideal pH level for a maximum degradation rate for many contaminants has been found to be between 7.0 and 8.0, with levels below 6.5 significantly slowing the activity of the microorganisms (Young 1995, p. 521). The best ratio of nutrients, C:N:P, is typically 100:10:1 (Norris 1993, p. 3), but biodegradation has been seen at nutrient concentrations as low as C:N of 200:1 and C:P of 1000:1 (Young 1995, p. 522).

Another environmental aspect important to the activity of microorganisms is the presence of elements which can be used as an electron acceptor to facilitate the chemical break-down process. Oxygen is the element most commonly used in this function. Various methods have been implemented in order to increase the oxygen levels including bioventing, air sparging and the injection of hydrogen peroxide beneath the surface of the plot (Young 1995, p. 523-530).

Anaerobic processes have also proven successful in the biodegradation of many contaminants. The anaerobic biodegradation process uses other compounds, such as nitrate, sulfate, and carbon dioxide instead of oxygen. These compounds are desirably because they are water soluble, inexpensive and nontoxic to the microorganisms (Norris 1993, p. 7-8). Studies have also been done showing the effectiveness of ferric iron as an electron acceptor for some types of contaminants (Caldwell 1999, p. 595-603).

Phytoremediation

Phytoremediation is the use of various types of plants to clean up pollutants in the environment. This bioremediation process has shown promise in the remediation of soil sediment, surface water and groundwater environments contaminated with toxic metals and organic pollutants (Salt *et al*., 1998).

Several different phytoremediation techniques are currently being studied. These have been described by (Raskin *et al.*, 1997) and include:

- *Phytoextraction, also called phytoaccumulation*: the use of pollutant-accumulating plants to remove contaminants from the soil and concentrate them in the above-ground shoots which can then be harvested. Metals are immutable and don't degrade.

- *Phytodegradation*: the use of plants to metabolize and destroy contaminants within plants tissues; transformation of toxic elements;

- *Phytovolatization*: the use of plants to take up water containing organic contaminants and volatize these contaminants into the air through the foliage;

- *Phytostabilization*: the use of plants to reduce the bioavailability of pollutants in the environment;

- *Rhizofiltration*: the use of plant roots to absorb and adsorb pollutants (mainly metals) from water and aqueous waste streams.

These techniques are all considered direct forms of phytoremediation. Indirect phytoremediation or phytoremediation *explanta* is remediation that occurs outside the plant in the soil and is based on root secretions (Salt *et al.* 1998).

Phytoremediation has been found to effectively treat the following contaminants: metals such as nickel, zinc, cadmium, lead, cobalt, copper, manganese, chromium and selenium (Reeves and Baker 2000), radionuclides, and a variety of organic contaminants including pesticides, petroleum hydrocarbons, ammunition wastes (TNT), polychlorinated phenols (PCBs), polycyclic aromatic hydrocarbons (PAHs) and halogenated solvents.

For the purposes of urban agriculture, rhizofiltration and phytostabilization are of limited use. Phytostabilization stabilizes pollutants in the soil thus rendering them harmless, but the contaminants are not actually removed. This would leave limited space on which to grow crops. Rhizofiltration, on the other hand, involves the absorption of contaminants that are in solution surrounding the root zone. The plants are used primarily to address contaminated groundwater rather than soil. Therefore, this phytoremediation technique is not applicable to terrestrial brownfields.

The most widely researched phytoremediation techniques are phytoextraction and phytodegradation. Phytoextraction comes in two forms: long term continuous phytoextraction and chelate-assisted phytoextraction, also known as induced phytoextraction. For continuous extraction some plants, known as hyper-accumulators, are able to absorb high quantities of heavy metals from the soil and concentrate them into the above-ground shoots. This is based on the genetic and physiological capacity of these specialized plants to accumulate, translocate and resist high amounts of metal in their tissues. The best known hyper-accumulators belong to the

Brassicaceae (Mustard) and Fabaceae (Bean) families. In 1998, the number of species which were capable of hyper-accumulation had grown to 397 and included 41 different plant families (Salt *et al.* 1998).

The drawbacks involved in using these naturally occurring metal hyper-accumulators for phytoextraction purposes are their relatively low biomass and their slow growth rates. Also, there is presently a lack of any hyperaccumulator species capable of removing the most environmentally important pollutants such as lead, cadmium, arsenic and radionuclides (Salt *et al*. 1998).

Induced phytoextraction, which has already been implemented commercially (Glass 2000), has solved some of the problems inherent in continuous extraction. Early studies performed by Jogensen (1993) showed that when synthetic metal chelates, such as EDTA, were applied to soil the accumulation of lead by non-hyperaccumulator plants was enhanced. This discovery paved the way for the development of phytoextraction of toxic metals using appropriate chelates (Salt *et al.* 1998).

The major advantage to using chelates is that fast-growing, high biomass plants such as sunflowers, corn and Indian mustard can be grown for the purposes of phytoextraction. This increases the efficiency of this technique because a greater amount of metal can be concentrated in the plants in a shorter time-frame by comparison to continuous extraction. Following harvest, the contaminated material can be further reduced by ashing and composting. The metal enriched plant residue can be disposed of as a hazardous material, or if economically feasible, used for metal recovery.

Phytodegradation is primarily used for the remediation of organic pollutants (Alkorta and Garbisu 2001). The goal of phytoremediation is to completely transform the contaminants into relatively non-toxic constituents such as carbon dioxide, nitrate, chlorine, and ammonia. Phytodegradation works in several different ways. Some plants release up to 20% of their photo-synthate into the soil via their roots (Anderson *et al.* 1994). This encourages microbial activity which speeds up degradation. Other plants release enzymes into the soil which break down pollutants directly (Salt *et al*. 1998). Most research on this technique has concentrated on the degradation of ammunition wastes such as TNT (Hannink *et al.* 2001). The bioavailability of organics in the soil appears to be the primary restriction for effective phytoremediation of organic pollutants (Meagher 2000).

Fungal Remediation

Fungal remediation techniques have been widely researched and have been proven to be effective in detoxifying soils contaminated with organic pollutants, although there are many limitations to this process, and further research on this technique is needed.

White rot fungi are wood-degrading basidiomycetes; in other words, they are the most active degraders of lignin, the most common polymer found in woody plants (Reddy and Mathew 2001, p. 53). Although white rot fungi have the ability to attack lignin, they also happen to produce non specific enzymes that have the power to degrade completely or decrease the toxicity of certain chemicals, including a broad range of halogenated and non-halogenated aromatic compounds as well as some non aromatic organo-pollutants. For example, in lab studies, *Phanerochaete chrysosporium*, a white rot fungi, can induce the breakdown of 70-100 % of 22 polycyclic aromatic hydrocarbons (Reddy and Mathew 2001, p.56).

White rot fungi have been the most studied in laboratories; however, other species of fungal inoculants, such as *P. sordida*, have also shown promise in decontaminating soils (Singleton 2001, p.91). For example, lab studies showed that the degradation of 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin by *P. sordida* was up to 60 % (Reddy and Mathew 2001, p.59).

As for soils contaminated with heavy metals, fungi such as mychorizas can increase the mobility of essential metal cations and anions by solubilization. Solubilization performed by mychorizas can mobilize metals into forms available for plant and microbial cellular uptake (Gadd 2001, p.359). For example, pyromorphite (Pb5(PO4)3Cl) can be solubilized by the fungi *Aspergillus niger* (Gadd 2001, p.362). The plants will therefore have the ability to uptake lead from the soil.

These experiments were performed under ideal laboratory conditions. White rot fungi were not as successful in biodegrading contaminants in field studies. They were unable to compete with native soil microbes for nutrients, and therefore did not reach their optimal productivity and nor did they have any beneficial effects (Reddy and Mathew 2001, p.70).

Also, unfavorable soil conditions, such as temperature, pH, and moisture content are also factors that inhibit the fungi in degrading organic soil pollutants. For example, the optimum growth temperature of *P. chrysosporium* is 40°C (Singleton 2001, p.82) which limits its potential in colder climates.

Compost

Compost is defined as a “dark earthly material which results from the natural decomposition of organic matter” (Recycling Council of Ontario 1990, p.1). A compost mixture includes soil, chopped vegetables, yard waste and trimmings, straw, hay, animal manure and anything else that is organic. This rich earth material converts available nitrogen, which would have been leached as nitrate into groundwater or released into the air as ammonia into organic nitrogen in the biomass (Abiola and Olenyk 1998, p.1), thus increasing productivity.

Compost has been proved effective in increasing soil fertility and has also been successful in degrading soil contaminants. For maximum efficiency in the decontamination process, it needs to be mixed with the decontaminated soil, and built in windrows (Goldstein 2000). Windrows are rows of compost and soil put out to dry in the open air by wind. However, compost in windrows works best for remediating petroleum hydrocarbons in army bases and landfills (Goldstein and Riggle 1995; Riggle 1995). When adding well mixed compost, soil temperature increases. This increase therefore provides a environment favorable to aerobic bacteria that biodegrade complex organic molecules such as hydrocarbons (Abiola and Olenyk 1998). Furthermore, compost is also used to treat soils contaminated with non-chlorinated and chlorinated semi-volatile and volatile organic compounds, BTEX (benzene, toluene, ethylbenzene and xylenes), pesticides and herbicides, explosives and propellants (Goldstein 2001). Compost also binds metals, making them unavailable to humans, plants and animals (Garland *et al.* 1995, p. 2).

Analytic Framework

Each soil remediation technique is different in the way in which it remediates soil, how much it costs, how long it takes, and who is qualified to apply it. Each technique will therefore differ in its appropriateness to community groups remediating for the purpose of urban agriculture. The following analytic framework was developed in order to assess the applicability and feasibility of each remediation technique, as well as to compare how each technique performs with respect to each criterion. This will enable community groups to select a technique best suited to their individual needs and requirements.

1. **Access**: How accessible is each remediation technique to community groups? Some techniques may still be in the developmental phase, and will therefore be inaccessible for implementation by community groups in the short term. Other techniques may not be available for implementation by non-experts. Techniques will be assessed with a Yes/No framework for accessibility.

2. **Cost**: The cost of each technique, from start to finish, is an extremely important second consideration. Most community groups operate on restricted budgets, making this an extremely important second criterion to consider when selecting a remediation technique. Cost will be assessed without considering consultation fees or soil testing, with techniques ranging from \$0-\$999, \$1 000-\$ 4 999, and \$5 000 and up for a plot of 20' x 6' x 2' (6.8 m^3, or approximately 9.5 metric tons of soil). Notes will be made for techniques requiring disposal and the addition of new soil. All prices are expressed in Canadian dollars.

3. **Timeframe**: Well-established and funded organizations may plan up to ten years into the future, while funding for younger or smaller groups may be insecure. Different amounts of time are required by each remediation technique to bring soil up to agricultural standards, as different groups can afford to allot different amounts of time to remediation projects. The timeframe considered is from the beginning of treatment to the point when the area is ready for planting and the range is as follows: < 1 season; 1 season < 1 year; 1 year < 5 years; > 5 years.

4. **Effectiveness for Urban Agriculture**: How effective is each remediation technique in bringing soil up to agricultural standards? Community groups are required to meet soil quality standards in order to practice urban agriculture, and there is a range in effectiveness

of each remediation technique to suit this particular purpose. Techniques will be ranked with respect to ability to bring soil to Quebec agricultural standards with 1 signifying unconditional effectiveness, 2 signifying conditional effectiveness and 3 signifying ineffectiveness.

5. **Environmental Effects**: Remediation techniques will vary in environmental soundness. Some have toxic by-products, others involve placing materials in the soil that are not biodegradable, and still others are completely organic. Community groups have different environmental mandates and will therefore have a range of acceptable limits in as to how environmentally sound the remediation technique they select is. Specific environmental effects will be listed for each technique.

Assessing and comparing remediation techniques based on the above criteria will give community groups a full understanding of the benefits and drawbacks of each technique. They will be able to select the technique with the best combination of characteristics for their unique context.

Below is a detailed description of the strengths and weaknesses of the remediation techniques. The summary table for the physical techniques can be found in Appendix F, and the table for the biological techniques can be found in Appendix G.

Excavation

Excavation is a quick, cost-intensive process. The cost of equipment rental, service, and disposal for a plot of 6-8 square meters would be approximately $600 (Notargiacomo 2002). Excavation is rated as a high-cost endeavor, however, because due to machine rental/labor costs, disposal fees and the price of new soil. This can be seen in the case study of the Phoenix Garden, in which the excavation project fell into our high cost category. The cost of each step of the process is outlined in Appendix I. Excavation can be done relatively quickly, and is practical for small plots of land. As for environmental consequences, it creates dust, allows volatiles to escape into the air, creates waste in the form of contaminated soil, and requires the use of fossil fuels for the excavation equipment and disposal trucks (T.M. Gates Inc 2002).

Geotextiles

Geotextiles are accessible in most areas, and are easily put into use. Expert advice is necessary for choosing the appropriate weight of the geotextile for a specific area, but a general guideline for agricultural purposes would be between 110-230 grams. Prices of geotextiles vary depending on the weights, and range from \$0.45-\$3.00/m^2 (Neubauer 2002). Although this is not a very expensive technology on its own, it is the excavatation of the contaminated soil prior to the impletation of the geotextile which tends to raise the cost. The time of implementation is minimal but will be extended slightly in conjunction with excavation . Geotextiles have a limited life span: after around 20 years they can lose their integrity and become porous to contaminants (Steinberg 1998). The synthetic fibers also take a long time to degrade once disposed of. Geotextiles are an inexpensive, easily implemented solution, but they have undesirable environmental consequences.

Soil Washing

Soil washing services are widely available, and the procedure is very effective at removing contaminants from the soil. Soil washing can reduce costs of remediating large areas because it reduces the amount of soil to be decontaminated. The total cost of soil washing includes the transportation of soil to the processing location or equipment to the site, cost of the washing process, disposal/treatment of the remaining contaminated soil, and the disposal of the wastewater used in the washing process (Wood 2002). Soil washing is in the medium cost range, though the costs will vary depending on the amount of soil to be processed and the contaminants present in the soil. Prices range from $110-$300/ton of soil (Ensley and Raskin 2000). For a sample garden plot of 6 ft by 20 ft, or approximately 6.8 cubic meters of contaminated soil, an average price would around $1000, including labor costs. The process for a plot this size would take between 3 to 12 hours, depending on transportation distances (Wood 2002). Disposal of contaminants remains an issue with this process, as soil washing simply concentrates contaminants in part of the soil and wastewater. This is more of an environmental impact concern than a practical one, as disposal is carried out by the soil washing company.

This process is relatively costly, but could fit into the budget of some community groups. It can be done quickly, but it does require the services of professionals. Its environmental consequences are not ideal, since it requires the use of water and energy resources, and essentially shifts the contaminants to a different location, rather than treating them.

Soil Vapor Extraction

Soil vapor extraction requires the installation of wells at the contaminated site. This in itself would cost $8,000. Prices for soil vapor extraction increase depending on the composition of the soil. Sand is the most porous, and therefore the easiest to process and the cheapest. Less porous soil can be processed at higher costs. A 5 ft by 5 ft by 10 ft column of sand contaminated with gas(hydrocarbons) would take approximately 30 days to decontaminate, at a cost of upwards of $30,000. A quarter acre of sandy soil could cost up to $ 250,000 for cleanup. Costs include the well installation, electricity ($800-$3,000), and equipment rental (several thousand). A general price index (without well installation) would be about $1500/ton (Malot 2002). Given that these are base price scenarios, and all other soil types will cost more, this process is not feasible for community groups. Environmental effects include air pollution from energy use and the disposal of contaminants in their vapor form

Microbial Remediation

The reliability of microbial remediation techniques has been well established through laboratory tests and case studies in the field. There are quite a few companies that assist in remediation of contaminated lands using microbial bioremediation techniques. They offer consultation and remediation products for remediation, regardless of location, making this technique accessible to almost anyone.

The cost of using bioremediation techniques to clean up a contaminated site depends on many different factors. These include the types of contaminants in the soil, the concentration of those contaminants, the size of the site being remediated, the desired level of contaminants after the treatment, and the natural soil conditions, including pH, soil density, concentration of nutrients, and oxygen levels. The costs for bioremediation, though variable, are seen as being lower than many other soil remediation techniques. The price estimate from one company is fifteen to twenty-five dollars (Canadian) per cubic meter or ten to twenty dollars per metric ton (Murland 2002), and another remediation company gives a price estimate of seventy dollars per cubic meter or fifty dollars per metric ton (Oppenheimer 2002).

The time frame for the remediation of the site to be completed depends on many of the same factors as stated above for the cost of the project. The time frame may also be adjusted depending on the budget available for the project (McGowen 2002). The remediation of most sites can be completed in a matter of weeks or months, with very few projects exceeding a time frame of one year (Oppenheimer 2002).

This method of remediation has proved effective in reducing the levels of contaminants to agricultural standards. Many microbial species are adept at breaking down most types of hydrocarbons and petroleum related by-products. Because of the ease with which hydrocarbons can be remediated through microbial processes, this is a very efficient method of remediating soil, even to the stringent levels of agricultural standards.

Microbial remediation of soil that is highly contaminated with heavy metals be problematic. It may be difficult to remediate soil containing high concentrations of contaminants to levels that are acceptable for agricultural purposes. There is also some concern with the potential conversion of stable metal complexes into more toxic ionic forms as a by-product of the microbial degradation processes. In many cases this has not been an issue, because the levels of heavy metals have not been much greater than the standards (Oppenheimer 2002). There are certain ions that can be effectively remediated, but the ability of the microbes to do this depends on the element and its ionic state (Oppenheimer 2002; Puzon 2002, p. 76-81). It is therefore important to be careful when remediating metals with this technique, and careful monitoring procedures should be exercised.

The most appealing aspect of microbial remediation is that it is an environmentally friendly way of cleaning the soil. Contaminants can be treated on site, with the only by-products of the decomposition process being carbon dioxide, fatty acids, and water (Ranart Environs 2002). Because the chemicals are degraded to a non-toxic state on site, this form of remediation is seen as environmentally sustainable, since there is no need to dispose of the soil or bring in new soil from another site. This also helps to reduce the cost of this technique since there is no cost of disposal for the contaminants.

Phytoremediation

At present, phytoremediation varies from being at a very early stage of commercial development (Glass 2000) to approaching commercialization (Garbisu and Alkorta 2001; Salt *et al.* 1998).

The greatest potential advantage of phytoremediation is its cost. The use of plants to remediate soil is cost-effective due to low capital and operating costs (Boyajian and Carreira 1997). Excluding monitoring and testing, the major expenses involved in phytoremediation are: tilling and preparation of the soil, irrigation (if applicable), planting the seeds, weed and pest control, harvesting, and in the case of phytoextraction, disposal of the biomass (Glass 2000).

An estimated price range for plant-based remediation is about $25-100 per ton (Glass 2000). The low end of this range typically applies to treatment of organic contaminants while the high end is an estimate for metals and radionuclides. As scale increases, costs decrease, making phytoremediation a cost-effective technique for the remediation of thousands of square kilometers of land (Meagher 2000).

In addition to low operating costs, metal recycling of hyperaccumulators can provide further economic advantages (Salt *et al.* 1998). Brooks *et al.* (1998) are looking into the possibility of mining certain metals using high-biomass plants that can accumulate large amounts of metals, aptly named phytomining. The time required for phytoremediation is the technique's greatest disadvantage. Neidorf (1996) estimates that in some cases, 18-60 months may be needed for complete remediation. In addition, due to the slow growth of natural hyperaccumulators, phytoremediation might even take 13-16 years to clean up a typical site (Boyd 1996; Salt *et al.*

1995). However, strategies are being explored to overcome this timeframe disadvantage. Chelating agents such as EDTA have improved the efficiency of phytoextraction (Salt *et al.* 1998), and the use of transgenic plants can also decrease remediation time (Raskin *et al.* 1997; Cunningham and Ow 1996). Furthermore, agronomic practices such as irrigation, fertilization, timing of planting and harvest and amendment addition will also increase the efficiency of phytoremediation, in turn decreasing the amount of time it takes to clean up sites (Ensley *et al.* 1997). There has been little research done using phytoremediation to remediate soil to meet agricultural standards. Phytoremediation is not very environmentally invasive, as the in situ method does not disturb the site. There are some negative environmental effects, mainly in the process of phytoextraction. Incineration of metal-accumulated biomass causes air pollution, and chelating agents may cause leaching if used improperly. Phytoextraction also transforms plants into hazardous material requiring disposal.

Fungal Remediation

There are no known examples of community organizations that have used fungi as a means for soil remediation, and therefore cost and time effectiveness cannot be determined at this point in time. Singleton (2001) states that chlorophenol levels in field studies were not reduced to those required for commercial, residential or agricultural use (p.91), and therefore this technique has not yet been proven effective for remediating contaminated soil for urban agriculture. Solubilization of insoluble toxic metal compounds in the soil may have unfavorable effects if toxic metal ions are released through this process (Gadd 2001, p.362).

Compost

Compost is available to everyone, and is therefore accessible to community groups. Producing a ton of compost including equipment amortization, labor and inputs will cost approximately $26 US (Grobe 2002, p.3), or $45 CAD per metric tonne. For community organizations such as the Food Project, who pursued urban agriculture projects, the cost of adding compost to contaminated soil was $30 per cubic yard (Brennan 2002) or $45 CAD per metric tonne. As for time effectiveness, compost cycles can last up to 14 weeks in the spring warm summer season for organic farming use (Grobe 2002, p.2). If phosphorus is added to the soil, the production time of compost can be reduced to three weeks (Garland *et al.* 1995, p.3). For community organizations, the addition of compost to contaminated soil only takes a few work days (Brennan 2002).

Like many soil decontamination techniques, there are limitations to using compost as well. One cannot use compost in windrows to remediate soil that will be used for agricultural purposes. Although compost binds to heavy metals such as lead, cadmium and zinc, in turn reducing their bioavailability to humans, plants and animals, no biodegradation occurs, leaving the contaminants present in the soil (Barbeau 2002; Hendershot 2002). This can pose a problem to community groups that need to reduce their levels of heavy metals to agricultural standards.

Compost is accessible and effective for community groups who wish to pursue urban agriculture. However, it cannot be used as a remediation technique. Compost mixed with decontaminated soil can be added to a site to serve as a barrier between the contaminated soil and the garden produce. Community organizations who wish to let people use a particular lot for gardening need to ensure that the roots of the plants being consumed will not reach the contaminated soil.

Compost is a time and cost effective method of degrading soil contaminants. It speeds up the decontamination process and prevents nutrient loss, making the soil more productive and less contaminated. However, though it reduces the bioavailability of the metals to humans, plants and animals, it cannot degrade them. Community groups need to test the soil quality regularly, along with the produce, to verify that heavy metals are not taken up by the plants that will be consumed. In addition, the barrier between the compost/soil mix and the roots needs to be ensured at all times.

Case Studies

The Food Project

The Food Project, a community organization based in Lincoln and Boston, Massachusetts, works with low-income gardeners farming in their own backyards. It provides workshops that promote organic agriculture and create awareness of the dangers of contaminated soils. It also helps gardeners remediate their soil through the input of compost and soil, phytoremediation, and the building of raised beds.

In the “Roxbury Fires” in the 70’s and 80’s, many of the homes in the Dudley neighborhood were burned down. Most of these homes were coated with lead paint, and as they burnt, the lead leached into the soil. Today many gardeners grow their produce where these houses were located. The Food Project helps these gardeners to reduce lead to appropriate levels that are safe for growing vegetables.

Through an environmental initiative grant program from the US Environmental Protection Agency, the Food Project funded their education outreach project. This project educates people about the potential hazards of urban soils and offers gardeners assistance with remediation.

To remediate these gardens, representatives of the Food Project follow a number of steps. First, they map the gardens and collect 4 or 5 soil samples. The samples are then taken to a testing lab, though recently on-site soil testing equipment provided by local universities and the Board of Public Health has been used. The soil is generally tested for lead, as this is the primary contaminant present in the soil. The University of Massachusetts Amherst soil testing lab charges $8 to$12 US ($13 to $19 CAD) per sample, depending on what needs to be tested. By gaining relationships with organizations and institutions, the Food Project also receives free soil testing.

Full remediation is done by bringing in enough soil and compost for there to be an adequate barrier between the contaminated soil and the garden vegetables. The soil must be deep enough so that the roots of the vegetables do not reach the contaminated soil. Follow-up soil tests are performed twice a year, and plants are also tested to ensure that no contaminants were absorbed in the tissues. Remediating two acres of land cost $26,600 US ($42,000 CAD). This amount included transportation costs and the purchasing of compost and soil for the lot to ensure that the mix was built up to two feet from the contaminated soil. A cubic yard of compost cost 30 dollars ($45 CAD per metric tonne) and 2 full dump truck loads were also donated by the city. Complete remediation was done for 6 gardens, and more than 75 gardens were partially remediated using a mix of compost and new soil. Setting up this form of remediation required only a few days work.

As for phytoremediation, which is cost effective, the Food Project encourages gardeners to plant mustards and sunflowers, two plants that are known to absorb lead. However due to the fact that many gardeners depend on their produce to feed their families, it is difficult for them to leave their land unproductive for a couple of seasons in order for phytoremediation to take place.

In addition to compost and phytoremediation, the Food Project has also built two raised beds for gardeners. This is cheaper than providing compost and soil, allows gardeners to continue gardening every season, and reduces vandalism. For a bed measuring 10 * 10 feet, material costs 300 dollars US ($450 CAD) and the soil/compost mix costs 200 dollars US ($300 CAD). It takes about two and a half hours to build a raised bed.

In conclusion, the Food Project is a practical case study of a community organization remediating contaminated land for urban agriculture, while promoting organic gardening and creating awareness of the health hazard effects of contaminants such as lead.

The Phoenix Garden

Eco-Initiatives, the client for this research project, undertook soil remediation to establish the Phoenix community garden on land provided by the Unitarian Church of Montreal. The garden project began when the UCM approached Eco-Initiatives with a site they wanted to develop into a community garden. The Church was built in 1995 and the garden was to be situated on a plot where a house once stood.

Eco-Initiatives approached *Bodycote Essais de Matériaux Canada Inc.*, who agreed to test the soil for contamination at no cost. Detailed results from the soil tests are in Appendix I. These results illustrate the importance of sampling and testing more than one area of the envisioned garden, as contamination levels differed between plots. For example, levels of polycyclic aromatic hydrocarbons (PAHs) were at high degrees of contamination in the North and East plots, and at intermediate degrees of contamination in the South and West plots. Soil analyses revealed high levels of PAHs, lead, zinc, and copper. Once the tests were completed, Eco-Initiatives determined that agriculture could not take place without remediation.

The options available in this case included bioremediation, container gardening, or using a geotextile membrane to seal of the garden site from the rest of the land and import new soil. It is this final technique that was selected, and garden development proceeded as follows. An area 6 x 20 feet was lined with geotextile along the bottom and sides, after the soil had been removed to another area of the surrounding land. Along all four sides of the garden, this geotextile was reinforced by heavy plastic sheets. On the bottom of the plot ¾ inches of gravel was laid, with another sheet of geotextile on top. 18 inches of new soil was brought in and laid on top of the geotextile to form the garden. Charlotte Gaudette was hired to provide garden plans, technical specifications, contact with a contractor, the planting plan, and other services at a cost of $3 000 before taxes. The total cost of the project was $17 197, not including the donations (soil testing and 33 shrubs). The specific breakdown of the costs is given in Appendix I.

Peculiarities of this Case

The UCM paid for the remediation and, in consultation with Eco-Initiatives, selected excavation because it represented the best combination of accessible, low-cost and quickly-implemented technology with the ability to bring soil up to agricultural standards. Excavation became cheaper because the contaminated soil did not have to be transported and dumped. It was simply placed in another area of the garden where vegetables were not going to be cultivated. It took 3 days to complete the entire process. This form of remediation will remain effective as long as the geotextile does not rip, as it will not biodegrade.

Conclusions

The emerging field of brownfield remediation for urban agriculture is an exciting option to put formerly contaminated and idle land to productive use by increasing urban food security and promoting community development through environmentally sound gardening. However, as an emerging field, there is substantial research yet to be done related to the feasibility for community groups of pursuing remediation options to prepare land for planting. There have been few such endeavours undertaken thus far, however the case studies provided demonstrate the practical side of soil remediation for urban agriculture. They are illustrative of the types of remediation, which groups are pursuing right now, as well as the particular challenges groups might come across, and opportunities for cost-saving measures including the provision of free soil testing by laboratories or the sponsoring of remediation projects by organizations such as the Unitarian Church of Montreal. Researching case studies provided insight not only into practicalities and peculiarities of remediation, but also to the fact that very few community groups are pursuing soil remediation, as it remains a domain largely in the hands of industry and government. Further, the few community groups who are in fact remediating are rarely planting crops for consumption post-remediation and are simply experimenting with process or planting ornamentals. Brownfield remediation for urban agriculture appears to remain a relatively unfeasible task for community groups.

Feasibility issues relate to the criteria discussed in our analytic framework, and the way in which many remediation techniques perform with respect to these criteria make pursuing certain solutions out of reach for many groups. For example, the cost and technical expertise required for soil washing and soil vapor extraction put them outside the feasible realm. The same is true for fungal remediation; however, in its case, due to lack of field research and the fact that the technique is in very early stages of development. There are no straightforward solutions to the problem of brownfield remediation for urban agriculture. The selection of an appropriate technique will depend on the needs, capabilities and constraints of individual groups as well as the particular soil characteristics, and the type and degree of contamination present. There is no technique that will be suitable to all groups and to all sorts of contamination problems. In light of these limitations, we have identified excavation as the most appropriate option for community groups to pursue at this time. It is accessible, cost- and time-effective, and represents the least amount of risk in bringing soil up to agricultural standards as well as maintaining these standards over the long term.

This element of risk raises important questions with respect to the other remediation techniques reviewed in this document. Microbial remediation and phytoremediation are very effective in removing the majority of contamination in a given plot. They are also both cost-effective and accessible to community groups. We have selected microbial remediation as the recommended biological remediation technique due to its advantage over phytoremediation with respect to time. However, both techniques have demonstrated difficulty in removing the final pollutants required to achieve agricultural-grade soil. Implementing geotextiles also involves a degree of risk in the material ripping or being punctured over time. If community groups wish to pursue these options, they must test soil often to ensure that agricultural quality requirements are achieved and that reversal does not take place. Because of the high health risk in the ingestion of food cultivated in contaminated soil, we recommend that community groups exercise the precautionary principle and employ excavation, the only feasible solution guaranteed to provide nutritious produce grown in a contaminant-free environment. It is especially important for community groups to consider this recommendation and to take responsibility for soil quality when encouraging individuals to participate in community gardening projects given that volunteers and community members are trusting that soil is suitable for growing.

In light of this recommendation, we recognize the great future potential of biological methods such as microbial and phytoremediation. With more research and time, these methods have the prospective of being risk-free and even more cost-effective than excavation, presenting exciting options for the future. One area if research not touched upon in this project is the possibility of combining remediation techniques to increase the pace, economic viability, and/or effectiveness of the remediation solution. There is the potential of combining physical with biological techniques, or pursuing combinations of purely physical or biological methods.

Community groups may pursue options to increase the financial viability of undertaking soil remediation for the purpose of urban agriculture. Limited by time, more detailed research into subsidy possibilities was not possible for this project.

However, we have established that although currently, subsidies are aimed at the revenue-generating side of remediation, there are many other benefits of remediation for urban agriculture. Some benefits, such as income supplementation, will be more easily expressed in monetary terms. Other benefits related to environmental sustainability, food security, and community development are less economically evident. In publicizing these benefits to solicit funds from the government, soil remediation could become more accessible for low-budget organizations in the future. This is an area of recommended continued research as an extension of this study.

Finally, by thinking creatively, community groups may wish to recast the problem of brownfield remediation for urban agriculture as “brownfields for urban agriculture” and pursue options that are not affected by urban soil contamination at all. Examples include container gardening and aquaponics. These techniques enable groups to achieve urban gardens, but without the cost, time requirements and risk of soil remediation at this time. Exploring such options makes urban agriculture feasible in the interim while research into remediation for small-scale, low budget urban projects develops and matures.

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Appendices

Appendix A

This questionnaire was administered by email, phone or in person to academics, experts and community groups.

1. What are the acceptable soil quality standards for urban agriculture, in terms of contaminant levels? What contaminants are absolutely unacceptable?
2. In your opinion, whose soil quality standards (federal, provincial or municipal governments) should community organizations follow? Should soil necessarily be up to agricultural grade before it is used for urban agriculture?
3. Remediation techniques that we have identified and are covering in our research include excavation, geotextiles, soil vapor extraction, soil washing, microbial remediation, phytoremediation, fungi remediation, and compost. Are there any new remediation techniques being researched that we might not have heard about yet?
4. How would you rate the effectiveness of these techniques in bringing soil up to agricultural standards?
5. What are the cost and time implications for these remediation techniques? Do any techniques have a short enough time frame and a low enough cost as to be useful to community groups (for example, less than 5 years)?
6. Overall, how would you rate these techniques from the perspective of community groups, considering effectiveness, time, cost, accessibility, and any other relevant factors?

7. Do you know of any examples of small-scale, low cost, urban soil remediation projects (for agriculture or otherwise)? If yes, please comment.
8. Do you know of any firms attempting soil remediation techniques for urban agriculture? If yes, please comment.
9. Are there any soil testing services available (companies, universities, government, or otherwise), which perform these soil tests at a relatively low cost?
10. Do you know of any examples of technical assistance or subsidies provided by government or private agencies to community groups in relation to soil remediation for urban agriculture?

The following questions will only be addressed to community that administer urban agriculture projects:

1. What was/is your budget for soil remediation projects for urban agriculture?
2. What is an acceptable time frame for you to undertake soil remediation for urban agriculture?
3. Have you undertaken any soil remediation projects in the past for urban agriculture?

If so, a) What technique(s) did you employ?

b) Was the project successful?

c) What was the time frame which encompassed the project?

d) What was the overall cost of the project?

e) What challenges/problems did you encounter?

List of People Interviewed:

Baker, L. Food Share, November 6th, 2002.

Barbeau, S. General Director of the Centre D'Excellence de Montréal en Réhabilitation de Sites. November 14th, 2002.

Berman, L. Food Share. November 10th, 2002.

Brennan, K. The Food Project. November 15th, 2002.

Gaudette, C. Landscape Architect, Mousse Inc. November 20th, 2002.

Ghoshal, S. Department of Civil Engineering, McGill University. November 25th, 2002.

Greer, C. Biotechnologist, NRC Biotechnology Research Institute. November 12th, 2002.

Hendershot, W. Professor of Soil Science, Department of Natural Resource Science, McGill University. November 13th, 2002.

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Murland, J. President, EnviroLogic Inc. / Spillaway. November 18th, 2002.

Neubauer, D. Geochem Inc. November 17th, 2002.

Notargiacomo, M. Canada Excavation. November 22nd, 2002.

Oppenheimer, C. Oppenheimer Biotechnology Inc. November 18th and 20th, 2002.

Wood, L. Terra Resources Ltd. November 17th, 2002.

Appendix B

Table 1. Canadian and Quebec Agricultural Soil Standards

Contaminant	Canada Standards Concentration (mg/kg)	Quebec Standards
Arsenic	12	6
Barium	750	200
Benzene	0.05	0.1
Non-chlorinated benzene compounds		
2,6-dinitrotoluene	-	0.7
Chlorobenzene	-	0.2
1,2-dichlorobenzene	-	0.2
1,3-dichlorobenzene	-	0.2
1,4-dichlorobenzene	-	0.2
Hexachlorobenzene	-	0.1
Pentachlorobenzene	-	0.1
1,2,3,4-tetrachlorobenzene	-	0.1
1,2,4,5-tetrachlorobenzene	-	0.1
1,2,3,5-tetrachlorobenzene	-	0.1
1,2,3-trichlorobenzene	-	0.1
1,2,4-trichlorobenzene	-	0.1
1,2,5-trichlorobenzene	-	0.1
Bromide	-	6
Cadmium	1.4	1.5
Carbon tetrachloride	-	0.1
Chlorinated ethanes		
1,1-dichloroethane	-	0.2
1,2-dichloroethane	-	0.2
1,1,1-trichloroethane	-	0.2
1,1,2-trichloroethane	-	0.2
Chlorinated ethenes		
1,1-dichloroethene	-	0.2
1,2-dichloroethene (cis and trans)	-	0.2
1,1,2-Trichloroethene (Trichloroethylene, TCE)	0.1	0.2
1,1,2,2-Tetrachloroethene (Tetrachloroethylene, PCE)	0.1	0.2
Chloroform	-	0.2
1,2-dichloropropane	-	0.2

1,3-dichloropropene (cis and trans)	-	0.2
Chromium	64	85
Hexavalent chromium (Cr(VI))	0.4	-
Cobalt	-	15
Copper	63	-
Cyanide	0.9	2
DDT (2,2-Bis(p-chlorophenyl)-1,1,1-trichloroethane;	0.7	-
Dichloro diphenyl trichloroethane)	-	-
Ethylbenzene	0.1	0.2
Ethylene glycol	960	-
Flouride	-	200
Formaldehyde	-	1
Lead	70	50
Manganese	-	770
Mercury	6.6	0.2
Molybdenum	-	2
Nickel	50	50
Petroleum hydrocarbons C10 to C50	-	300
Phenols	3.8	-
Chlorophenol (2,3, or 4)	-	0.1
2,3-dichlorophenol	-	0.1
2,4-dichlorophenol	-	0.1
2,5-dichlorophenol	-	0.1
2,6-dichlorophenol	-	0.1
3,4-dichlorophenol	-	0.1
3,5-dichlorophenol	-	0.1
Pentachlorophenol (PCP)	7.6	0.1
2,3,4,5-tetrachlorophenol	-	0.1
2,3,4,6-tetrachlorophenol	-	0.1
2,3,5,6-tetrachlorophenol	-	0.1
2,3,4-trichlorophenol	-	0.1
2,3,5-trichlorophenol	-	0.1
2,3,6-trichlorophenol	-	0.1
2,4,5-trichlorophenol	-	0.1
2,4,6-trichlorophenol	-	0.1
3,4,5-trichlorophenol	-	0.1
chlorinated Phenols		
Cresol (ortho, meta, para)	-	0.1
2,4-dimethylphenol	-	0.1
2,4-dinitrophenol	-	0.1
2,4-dinitrocresol	-	0.1

2-nitrophenol	-	0.5
4-nitrophenol	-	0.5
Phenol	-	0.1
Polychlorinated biphenyls (PCBs)	0.5	0.05
Polycyclic aromatic hydrocarbons (PAHs)		
Benzo(b+j+k)fluoranthrene	-	0.1
Benzo(c)phenanthrene	-	0.1
Benzo(g,h,i)perylene	-	0.1
Chrysene	-	0.1
Dibenzo(a,h)anthracene	-	0.1
Dibenzo(a,i)pyrene	-	0.1
Dibenzo(a,h)pyrene	-	0.1
Dibenzo(a,l)pyrene	-	0.1
7,12-dimethylbenzo(a)anthracene	-	0.1
Flouranthene	-	0.1
Fluorene	-	0.1
Indeno(1,2,3-cd)pyrene	-	0.1
3-methylcholanthrene	-	0.1
Methyl naphthalenes	-	0.1
Naphthalene	0.1	0.1
Phenanthrene	-	0.1
Pyrene	-	0.1
Selenium	-	1
Silver	-	2
Styrene	-	0.2
Sulpher	-	400
Thallium	1	-
Tin	-	5
Toluene	0.1	0.2
Vanadium	130	-
Vinyl chloride	-	0.4
Xylene	0.1	0.2
Zinc	200	110

From: Canadian environmental quality guidelines. 1999. Winnipeg : Canadian Council of Ministers of the Environment.

Appendix C

The following sources are found in Montreal, and are presented to demonstrate the types of resources publicly accessible for land use history queries. Community groups in other cities can find the equivalent.

1. **Cartotheque (map library)**, Université de Québec à Montréal
   Location: Bibliothèque Generale (Pavillon Hubert-Aquin), 400 rue Sainte-Catherine Est
   Website: http://www.bibliotheques.uqam.ca/bibliotheques/cartotheque/index.html
   Note: Accessible by appointment only

2. **Cartotheque**, Bibliothèque Nationale du Québec
   Location: 2275 rue Holt
   Website: http://www.bnquebec.ca
   Online historical maps: http://www.bnquebec.ca/cargeo/accueil.htm

3. **Cartotheque**, Université de Montréal
   Location: 520 chemin de la Côte-Ste-Catherine, Room 232
   Note: Accessible by appointment only

4. **City of Montreal Archives**
   Location: 275 rue Notre-Dame Est, Room 108
   Website: http://www2.ville.montreal.qc.ca/archives/archives.html

5. **Palais de Justice de Montréal**
   Location: 155 rue Notre-Dame Est
   Website: http://www.barreau.qc.ca/montreal/Ang/pages/AV_06.htm

6. **Répertoire des terrains contaminés** – Environnement Québec
   Website: http://www.menv.gouv.qc.ca/sol/terrains/terrains-contamines/recherche.asp

7. **Walter Hitschfeld Geographic Information Center**, McGill University
   Location: 805 rue Sherbrooke Ouest
   Website: http://www.library.mcgill.ca
   Email: gic.library@mcgill.ca

Appendix D

Table 2. Contaminants That May be Produced by Various Land Uses

COMMERCIAL / INDUSTRIAL	
Above-ground Storage Tanks	
Automobile, Body Shops/Repair Shops	
Boat Repair/Refinishing/Marinas	
Cement/Concrete Plants	
Chemical/Petroleum Processing	
Construction/Demolition	
Dry Cleaners/Dry Cleaning	
Dry Goods Manufacturing	
Electrical/Electronic Manufacturing	

Fleet/Trucking/ Bus Terminals	
Food Processing	
Funeral Services/Taxidermy	
Furniture Repair/Manufacturing	
Gas Stations *(see also above ground/underground storage tanks, motor-vehicle drainage wells)*	
Hardware/Lumber/Parts Stores	
Historic Waste Dumps/Landfills	
Home Manufacturing	
Industrial Waste Disposal Wells	Dichlorobenzene or O-Dichlorobenzene, 1,4-Dichlorobenzene or p-Dichlorobenzene, 1,1-Dichloroethylene, cis 1,2 Dichloroethylene, Dichloromethane, Di(2-ethylhexyl) phthlate, 1,2-Dichloroethane, Hexachlorobenzene, Lead, Mercury, Polychlorinated Biphenyls, Selenium, Styrene, Sulfate, Tetrachloroethylene, Toluene, 1,2,4-Trichlorobenzene, 1,1,1-Trichloroethane, Trichloroethylene (TCE), Vinyl Chloride, Xylene (Mixed Isomers), Zinc (Fume or Dust)
Junk/Scrap/Salvage Yards	
Machine Shops	

Medical/Vet Offices	
Metal Plating/Finishing/Fabricating	
Military Installations	
Mines/Gravel Pits	
Motor Pools	
Motor Vehicle Waste Disposal Wells (gas stations, repair shops) *See UIC for more on concerns for these sources* *http://www.epa.gov/safewater/uic/cv-fs.html*	

Underground Storage Tanks	
Wood Preserving/Treating	
Wood/Pulp/Paper Processing	
RESIDENTIAL / MUNICIPAL	
Airports (Maintenance/Fueling Areas)	
Apartments and Condominiums	
Camp Grounds/RV Parks	
Cesspools - Large Capacity	
Drinking Water Treatment Facilities	
Gas Pipelines	
Golf Courses and Urban Parks	
Housing developments	

Landfills/Dumps	
Public Buildings *(e.g., schools, town halls, fire stations, police stations)* ***and Civic Organizations***	
Septic Systems	
Sewer Lines	
Stormwater Infiltration Basins/Injection into Wells, Runoff Zones	
Utility Stations	
Waste Transfer/Recycling	
Wastewater Treatment Facilities/Discharge Locations (including land disposal and underground injection of sludge)	
AGRICULTURAL / RURAL	
Auction Lots/Boarding Stables	
Animal Feeding Operations/Confined Animal Feeding Operations	
Bird Rookeries/Wildlife feeding /Migration Zones	
Crops – Irrigated/Non-irrigated	
Dairy operations	
Drainage Wells, Lagoons, Liquid Waste disposal	
Rangeland/Grazing lands	
Residential Wastewater Lagoons	
Rural Homesteads	

MISCELLANEOUS SOURCES	
Abandoned Drinking Water Wells	

Source: US Environmental Protection Agency. 2002. http://www.epa.gov

Appendix E

Table 3. Partial listing of private and provincial soil testing laboratories in Canada

Province	Laboratory
Alberta	**Alberta Soils and Animal Nutrition Laboratory** **Norwest Labs** 9938-67 Ave., Edmonton, AB, T6H 4P2 (708) 438-5522 or (800) 661-7645 http://www.norwestlabs.com
British Columbia	**Griffin Labs Corp.** 1875 Spall Road, Kelowna, BC, V1Y 4R2 (250) 861-3234
Manitoba	104, 19575-56A Avenue, Surrey, BC, V3S 8P8 (604) 514-3322 or (800) 889-1433 http://www.norwestlabs.com **Pacific Soil Analysis** Unit #5, 11720 Voyageur Way, Richmond, BC, V6X 3G9 (604) 273-8226 **Manitoba Provincial Soil Testing Lab**
New Brunswick	**Norwest Labs** **NB Agricultural Lab** NB Dept. Of Agriculture and Rural Development, Box 6000, Fredericton, NB, E3B 5H1 (506) 453-2666 or (888) 622-4742 http://www.nbfarm.com/genfaqs.htm
Newfoundland & Labrador	**Soil Plant and Feed Laboratory** Department of Forest Resources and Agrifoods, Provincial Agriculture Building, Box 8700, Brookfield Road, St. John's, NF, A1B 4J6 (709) 729-6638 http://www.gov.nf.ca/agric/telephon/ferspec.htm

Nova Scotia	**Soils and Crops Branch** Nova Scotia Department of Agriculture and Fisheries, Box 550, Truro, NS, B2N 5E3 (902) 895-4469 http://www.gov.ns.ca/nsaf/qe/analytical/soilsamp.htm 176 College Road, Harlow Institute, Box 550, Truro, NS, B2N 5E3 (902) 893-7444 http://www.gov.ns.ca/nsaf/qe/analytical/soilsamp.htm
Ontario	**A & L Canada Laboratories East, Inc.** **Accutest Laboratories** **Agri-Food Laboratories** **Nutrite** **Ontario Ministry of Agriculture** Food & Rural Affairs, Agricultural Information Contact Centre (877) 424-1300 http://www.gov.on.ca/OMAFRA/english/crops/resource/soillabs.htm **Royal Botanical Gardens** **Soil and Nutrient Laboratory** 1131 Erie St., Box 760, Stratford, ON, N5A 6W1 (519) 273-4411 or (800) 323-9089 http://www.stratfordagri.com
Prince Edward Island	P.O. Box 1600, Research Station, Charlottetown, PE, C1A 7N3 (902) 368-5631 http://www.gov.pe.ca/af/soilfeed/index.asp *Will give organic results, if requested. Samples may also be left at your nearest District Agricultural Office.*

Quebec	Box 1000, Brossard, QC, J4Z 3N2 (514) 462-2555 *Will give organic results.* **B E B Bureau D'Etude Du Bâtiment** beb@qc.aira.com **Bodycote Essais de Materiaux Canada, Inc** **Inspec-Sol Inc** **Laboratoire Sondage Universel Inc** 3080, rue Brabant-Marineau, Saint-Laurent, QC, H4S 1K7 (514) 332-0422 info@laboratoireuniversel.com
	Saskatchewan Soil Testing Lab **Enviro-Test Laboratories**

Adapted from: Canadian Gardening website. 2002.
http://www.canadiangardening.com/HTML/cg_soiltesting.html

Appendix F

Table 4. Analytic Framework Applied to Physical Remediation Techniques

	Excavation	Geotextiles	Soil washing	Soil vapor extraction
Access	**yes**	yes	yes	yes
Cost ($CAD)	**$5000 - $10 000**	< $1000 + excavation costs	$1000 - $5000	$10 000 +
Time Frame	**short < 1 season**			
Effectiveness for UA		2	1	1
Environmental Effects	**disposal energy use air pollution**	disposal energy use air pollution	disposal energy use air pollution	disposal energy use air pollution

Appendix G

Table 5. Analytic Framework Applied to Biological Remediation Techniques

	Microbial remediation	Phyto-remediation	Fungal remediation	Compost
	yes			
	< $1000		n/a	< $1000
	short < 1 year	2-5+ years	n/a	short < 1 season
	2		3	2-3
	potential metal toxicity	disposal of toxic plants	potential metal toxicity	none

Appendix H

Table 6. Complete Soil Test Results for the Phoenix Garden

North Sample

Contaminant	Concentration in Sample	Acceptable level for Agriculture (Quebec)	Soil Grade (A, B, C)
	<0.1 mg/kg	<0.1 mg/kg	A
Toluene	<0.1 mg/kg	<0.2 mg/kg	A
Ethylbenzene	<0.1 mg/kg	<0.2 mg/kg	A
Xylenes	<0.1 mg/kg	<0.2 mg/kg	A
Naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-2 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-1 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Dimethyl-1,3 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Acenaphthylene	0.6 mg/kg	<0.1 mg/kg	B
Acenaphtene	0.2 mg/kg	<0.1 mg/kg	A
Trimethyl-2,3,5 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Fluorene	0.4 mg/kg	<0.1 mg/kg	B
Phenanthrene	3.8 mg/kg	<0.1 mg/kg	B
Anthracene	1.3 mg/kg	<0.1 mg/kg	B
Fluoranthene	7.2 mg/kg	<0.1 mg/kg	B
Pyrene	6.1 mg/kg	<0.1 mg/kg	B
7, 12-dimethylbenzoanthracene	<0.1 mg/kg	<0.1 mg/kg	A
Benzo (g,h,i) perylene	2.3 mg/kg	<0.1 mg/kg	C
Benzo (c) phenanthrene	0.5 mg/kg	<0.1 mg/kg	C
Chrysene	3.7 mg/kg	<0.1 mg/kg	C
Benzo (a) anthracene	3.4 mg/kg	<0.1 mg/kg	C
Benzo (b,j,k) fluoranthene	5.8 mg/kg	<0.1 mg/kg	C
Benzo (a) pyrene	3.3 mg/kg	<0.1 mg/kg	C
3-methylcholanthrene	<0.1 mg/kg	<0.1 mg/kg	A
Indeno (1,2,3-cd) pyrene	2.3 mg/kg	<0.1 mg/kg	C
Dibenzo (ah) anthracene	0.8 mg/kg	<0.1 mg/kg	B
Dibenzo (a,l) pyrene	<0.1 mg/kg	<0.1 mg/kg	A

Dibenzo (a,i) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,h) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
2-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,6-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,5-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Pentachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Phenol	<0.1 mg/kg	<0.1 mg/kg	A
o-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
m-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
p-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
2-nitrophenol	<0.1 mg/kg	0.5 mg/kg	A
2,4-dimethylphenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dinitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-nitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
2-methyl-4,6-dinitrophenol	<0.1 mg/kg	-	A

South Sample

Contaminant	Concentration in Sample	Acceptable level for Agriculture	Soil Grade (A, B, C)
Cadmium	<0.1 mg/kg	1.5 mg/kg	A
Chrome	13 mg/kg	1.5 mg/kg	A
Copper	59 mg/kg	63 mg/kg	B
Nickel	20 mg/kg	50 mg/kg	A
Lead	160 mg/kg	50 mg/kg	B

Zinc	190 mg/kg	110 mg/kg	A/B
Benzene	<0.1 mg/kg	<0.1 mg/kg	A
Toluene	<0.1 mg/kg	<0.2 mg/kg	A
Ethylbenzene	<0.1 mg/kg	<0.2 mg/kg	A
Xylenes	<0.1 mg/kg	<0.2 mg/kg	A
Naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-2 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-1 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Dimethyl-1,3 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Acenaphthylene	<0.1 mg/kg	<0.1 mg/kg	A
Acenaphtene	<0.1 mg/kg	<0.1 mg/kg	A
Trimethyl-2,3,5 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Fluorene	<0.1 mg/kg	<0.1 mg/kg	A
Phenanthrene	0.8 mg/kg	<0.1 mg/kg	B
Anthracene	0.3 mg/kg	<0.1 mg/kg	B
Fluoranthene	1.0 mg/kg	<0.1 mg/kg	B
Pyrene	0.9 mg/kg	<0.1 mg/kg	B
7, 12-dimethylbenzoanthracene	<0.1 mg/kg	<0.1 mg/kg	A
Benzo (g,h,i) perylene	0.4 mg/kg	<0.1 mg/kg	B
Benzo (c) phenanthrene	<0.1 mg/kg	<0.1 mg/kg	A
Chrysene	0.5 mg/kg	<0.1 mg/kg	B
Benzo (a) anthracene	0.7 mg/kg	<0.1 mg/kg	B
Benzo (b,j,k) fluoranthene	1.0 mg/kg	<0.1 mg/kg	B
Benzo (a) pyrene	0.5 mg/kg	<0.1 mg/kg	B
3-methylcholanthrene	<0.1 mg/kg	<0.1 mg/kg	A
Indeno (1,2,3-cd) pyrene	0.4 mg/kg	<0.1 mg/kg	B
Dibenzo (ah) anthracene	0.4 mg/kg	<0.1 mg/kg	B
Dibenzo (a,l) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,i) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,h) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
2-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,6-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A

2,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,5-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Pentachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Phenol	<0.1 mg/kg	<0.1 mg/kg	A
o-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
m-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
p-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
2-nitrophenol	<0.1 mg/kg	0.5 mg/kg	A
2,4-dimethylphenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dinitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-nitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
2-methyl-4,6-dinitrophenol	<0.1 mg/kg	-	A

East Sample

Contaminant	Concentration in Sample	Acceptable level for Agriculture	Soil Grade (A, B, C)
Cadmium	1.0 mg/kg	1.5 mg/kg	A
Chrome	9.0 mg/kg	1.5 mg/kg	A
Copper	54 mg/kg	63 mg/kg	B
Nickel	16 mg/kg	50 mg/kg	A
Lead	390 mg/kg	50 mg/kg	B
Zinc	450 mg/kg	110 mg/kg	B
Benzene	<0.1 mg/kg	<0.1 mg/kg	A
Toluene	<0.1 mg/kg	<0.2 mg/kg	A
Ethylbenzene	<0.1 mg/kg	<0.2 mg/kg	A
Xylenes	<0.1 mg/kg	<0.2 mg/kg	A
Naphtalene	0.4 mg/kg	<0.1 mg/kg	B
Methyl-2 naphtalene	0.4 mg/kg	<0.1 mg/kg	B
Methyl-1 naphtalene	0.3 mg/kg	<0.1 mg/kg	B
Dimethyl-1,3 naphtalene	0.3 mg/kg	<0.1 mg/kg	B
Acenaphthylene	0.5 mg/kg	<0.1 mg/kg	B
Acenaphtene	0.9 mg/kg	<0.1 mg/kg	B
Trimethyl-2,3,5 naphtalene	0.2 mg/kg	<0.1 mg/kg	B
Fluorene	1.4 mg/kg	<0.1 mg/kg	B
Phenanthrene	11 mg/kg	<0.1 mg/kg	C

Anthracene	3.5 mg/kg	<0.1 mg/kg	B
Fluoranthene	14 mg/kg	<0.1 mg/kg	C
Pyrene	11 mg/kg	<0.1 mg/kg	C
7, 12-dimethylbenzoanthracene	<0.1 mg/kg	<0.1 mg/kg	A
Benzo (g,h,i) perylene	3.1 mg/kg	<0.1 mg/kg	C
Benzo (c) phenanthrene	0.9 mg/kg	<0.1 mg/kg	-
Chrysene	6.5 mg/kg	<0.1 mg/kg	C
Benzo (a) anthracene	6.6 mg/kg	<0.1 mg/kg	C
Benzo (b,j,k) fluoranthene	6.7 mg/kg	<0.1 mg/kg	C
Benzo (a) pyrene	4.9 mg/kg	<0.1 mg/kg	C
3-methylcholanthrene	<0.1 mg/kg	<0.1 mg/kg	A
Indeno (1,2,3-cd) pyrene	3.2 mg/kg	<0.1 mg/kg	C
Dibenzo (ah) anthracene	1.1 mg/kg	<0.1 mg/kg	B
Dibenzo (a,l) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,i) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,h) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
2-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,6-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,5-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Pentachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Phenol	<0.1 mg/kg	<0.1 mg/kg	A
o-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
m-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
p-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
2-nitrophenol	<0.1 mg/kg	0.5 mg/kg	A
2,4-dimethylphenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dinitrophenol	<0.1 mg/kg	<0.1 mg/kg	A

4-nitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
2-methyl-4,6-dinitrophenol	<0.1 mg/kg	-	A

West Sample

Contaminant	Concentration in Sample	Acceptable level for Agriculture	Soil Grade (A, B, C)
Cadmium	<0.1 mg/kg	1.5 mg/kg	A
Chrome	12 mg/kg	1.5 mg/kg	A
Copper	48 mg/kg	63 mg/kg	A/B
Nickel	31 mg/kg	50 mg/kg	A
Lead	110 mg/kg	50 mg/kg	A/B
Zinc	170 mg/kg	110 mg/kg	A/B
Benzene	<0.1 mg/kg	<0.1 mg/kg	A
Toluene	<0.1 mg/kg	<0.2 mg/kg	A
Ethylbenzene	<0.1 mg/kg	<0.2 mg/kg	A
Xylenes	<0.1 mg/kg	<0.2 mg/kg	A
Naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-2 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Methyl-1 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Dimethyl-1,3 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Acenaphthylene	<0.1 mg/kg	<0.1 mg/kg	A
Acenaphtene	<0.1 mg/kg	<0.1 mg/kg	A
Trimethyl-2,3,5 naphtalene	<0.1 mg/kg	<0.1 mg/kg	A
Fluorene	0.1 mg/kg	<0.1 mg/kg	A
Phenanthrene	1.2 mg/kg	<0.1 mg/kg	B
Anthracene	0.4 mg/kg	<0.1 mg/kg	B
Fluoranthene	2.2 mg/kg	<0.1 mg/kg	B
Pyrene	2.0 mg/kg	<0.1 mg/kg	B
7,12-dimethylbenzoanthracene	<0.1 mg/kg	<0.1 mg/kg	A
Benzo (g,h,i) perylene	0.7 mg/kg	<0.1 mg/kg	B
Benzo (c) phenanthrene	0.2 mg/kg	<0.1 mg/kg	B
Chrysene	1.2 mg/kg	<0.1 mg/kg	B
Benzo (a) anthracene	1.2 mg/kg	<0.1 mg/kg	B
Benzo (b,j,k) fluoranthene	2.1 mg/kg	<0.1 mg/kg	A/B
Benzo (a) pyrene	1.0 mg/kg	<0.1 mg/kg	B
3-methylcholanthrene	<0.1 mg/kg	<0.1 mg/kg	A
Indeno (1,2,3-cd) pyrene	0.7 mg/kg	<0.1 mg/kg	B
Dibenzo (ah) anthracene	0.4 mg/kg	<0.1 mg/kg	B
Dibenzo (a,l) pyrene	<0.1 mg/kg	<0.1 mg/kg	A

Dibenzo (a,i) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
Dibenzo (a,h) pyrene	<0.1 mg/kg	<0.1 mg/kg	A
2-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-chlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,6-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,5-dichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4,6-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
3,4,5-trichlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,5-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,4,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
2,3,5,6-tetrachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Pentachlorophenol	<0.1 mg/kg	<0.1 mg/kg	A
Phenol	<0.1 mg/kg	<0.1 mg/kg	A
o-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
m-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
p-Cresol	<0.1 mg/kg	<0.1 mg/kg	A
2-nitrophenol	<0.1 mg/kg	0.5 mg/kg	A
2,4-dimethylphenol	<0.1 mg/kg	<0.1 mg/kg	A
2,4-dinitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
4-nitrophenol	<0.1 mg/kg	<0.1 mg/kg	A
2-methyl-4,6-dinitrophenol	<0.1 mg/kg	-	A

Source: Bodycote Essais de Materiaux Canada Inc. (2001)

Appendix I

Cost Breakdown of the Phoenix Garden

Organization of the work-site:	$385.00
Demolition, abduction and recuperation:	$385.00
Labor for excavation and refilling:	$1 375.00
Dust rock surface:	$770.00
Edges in modulate concrete:	$2 398.00
Plastic edging:	$4 180.00
Gardening area:	$2 478.00
Plants:	$770.00
Special tasks:	$66.00
Contingencies:	$1 359.00
Total:	**$13 592.00**
GST:	$1 046.00
PST:	$1 199.00
TOTAL	**$17 197.00**

Note: This breakdown does not include consultation fees.